NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AUTONOMOUS-AGENT BASED SIMULATION OF ANTI-SUBMARINE WARFARE OPERATIONS WITH THE GOAL OF PROTECTING A HIGH VALUE UNIT

by

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March 2004

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2004	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Autonomous-Agent Based Simulation of Anti-Submarine Warfare Operations with the Goal of Protecting a High Value Unit			**5. FUNDING NUMBERS**
6. AUTHOR(S) Fahrettin Akbori			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The Anti-Submarine Warfare screen design simulation is a program that provides a model for operations in anti-submarine warfare (ASW). The purpose of the program is to aid ASW commanders, allowing them to configure an ASW screen, including the sonar policy, convoy speed, and the number of ships, to gain insight into how these and other factors beyond their control, such as water conditions, impact ASW effectiveness. It is also designed to be used as a training tool for ASW officers. The program is implemented in Java programming language, using the Multi Agent System (MAS) technique. The simulation interface is a Horizontal Display Center (HDC) which is very similar to a MEKO200 class Frigate Combat Information Center's (CIC) HDC. The program uses Extensible Markup Language (XML) files for reading data for program scenarios; parameters are initialized before each run time begins. The simulation also provides all the output data at the end of run time for analysis purposes. The program user's goal, and the purpose of the program, is to decrease the number of successful attacks against surface vessels by changing the configuration parameters of the ASW screen, to reflect sonar policy, convoy speed or number of ships in the simulation. Ongoing use of the program can provide data needed to anticipate required operational needs in future ASW situations.

14. SUBJECT TERMS Anti-Submarine Warfare (ASW), Anti-Submarine Warfare (ASW) Screen, Multi Agent Systems, Artificial Intelligence, Protection of High Value Unit (HVU), Combat Information Center (CIC), Naval Simulations, Combat Information Center (CIC) Watch Officer, Sonar Detection, Submarine Torpedo Attack, Decision Making, Cognitive Factors			**15. NUMBER OF PAGES** 124
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN
MODELING, VIRTUAL ENVIRONMENTS AND SIMULATION (MOVES)

from the

NAVAL POSTGRADUATE SCHOOL
March 2004

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ABSTRACT

The Anti-Submarine Warfare screen design simulation is a program that provides a model for operations in anti-submarine warfare (ASW). The purpose of the program is to aid ASW commanders, allowing them to configure an ASW screen, including the sonar policy, convoy speed, and the number of ships, to gain insight into how these and other factors beyond their control, such as water conditions, impact ASW effectiveness. It is also designed to be used as a training tool for ASW officers. The program is implemented in Java programming language, using the Multi Agent System (MAS) technique. The simulation interface is a Horizontal Display Center (HDC) which is very similar to a MEKO200 class Frigate Combat Information Center's (CIC) HDC. The program uses Extensible Markup Language (XML) files for reading data for program scenarios; parameters are initialized before each run time begins. The simulation also provides all the output data at the end of run time for analysis purposes. The program user's goal, and the purpose of the program, is to decrease the number of successful attacks against surface vessels by changing the configuration parameters of the ASW screen, to reflect sonar policy, convoy speed or number of ships in the simulation. Ongoing use of the program can provide data needed to anticipate required operational needs in future ASW situations.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

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ACKNOWLEDGMENTS

I would like to thank my advisor Professor Christian Darken and Professor John Hiles and Mr. Curt Blais for their expert knowledge and support. Without their guidance and advice, I could not have completed this project. I would also like to thank Ms. Barbara Young for her patience in editing my thesis. Most of all, I am very grateful to Ms. Caitlyn Nguyen and Lieutenant Junior Grade Baris Egemen Ozkan for their assistance and moral support.

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I. INTRODUCTION

A. WHAT IS SIMULATION?

Simulation is designing a model of an actual system in the computer to imitate reality. By using the simulation, the user learns through doing. For example, a child understands the world by simulating with toys or role-playing. During role-play, a child will experiment with interactions between objects--playing with human and animal figurines or crashing toy cars together and observing the results of the collision. Artificial objects are constructed and the roles between them are analyzed to capture the complexity of reality. A computer simulation is a representation of role-playing in a synthetic environment or virtual world.[1]

Three steps are involved in a simulation: model design and model implementation, model execution, and model analysis. A model design is constructed to answer a real world problem. It is a mathematical model that represents a physical object and may be a declarative, functional, constraint, spatial or hybrid model. After construction of a model design, the next step is to execute the model. The model can be executed by creating a computer program to run the mathematical model with input parameters and deriving outputs. Model analysis explores the relationship between the input parameters and the output data. The analysis tells a story of what happened during a simulation and tries to answer a question.

B. WHY DO SIMULATION?

A simulation is used to study complex, dynamic systems. Simulation is essential in the following cases: 1) the model has many variables and interacting components, 2) the relationships between the variables are not linear, 3) the model has random variables, 4) the model output is a visual rendering such as a

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[1] Fishwick, P., cited 2004: What is simulation? [Available online at http://www.cis.ufl.edu/~fishwick/introsim/node1.html.]

three-dimensional computer animation.[2] Simulation is used to visualize a large variety of non-linear systems and behavior or to replicate the actual system.

Since a simulation has predictive capabilities the program user can make better decisions through optimization and control. A simulation is a computational laboratory experiment that provides the program user with a greater understanding of the sensitivities of parameters and scale-up information. The simulation can be used to isolate and combine phenomena.[3]

C. BENEFITS OF SIMULATION IN MILITARY APPLICATIONS

Simulation used in military operations is an efficient and cost-effective way of preparing and training military personnel. In the modern military environment, weapon systems and vehicles are increasingly expensive to operate. Realistic training using actual systems is more difficult due to safety and environmental issues.[4] Simulation is a better approach to preparing an operation as well training military personnel. Simulations also help military commanders make decisions based on model combat and subsequent analysis modeling integrating the platforms, sensors, and weapons into a simulated environment.

D. APPLICATION OF SIMULATION FOR ANTI-SUBMARINE WARFARE

In this research thesis, a model design is used to simulate Anti-Submarine Warfare (ASW) operations incorporating High-Value Unit (HVU) protection. This simulation can be used to train ASW officers. They will become acquainted with ASW operations through computer-generated visualization. ASW commanders can analyze the output and configure better ASW screen designs to prepare and plan an operation.

[2] Fishwick, P., cited 2004: Why do simulation? [Available online at http://www.cis.ufl.edu/~fishwick/introsim/node2.html.]

[3] Ewing R. and R. Sharpley, cited 2004: Interactive control of large-scale simulations. [Available online at http://www.cise.nsf.gov/cns/darema/dd_das/ew_ing/sld010.htm.]

[4] Wilton D. R., 2004: Demonstrating the benefits of simulation in a military environment. *J. Battlefield Tech.,* **7,** 31-37

The simulation program is created in JAVA programming language using multi-agent system (MAS) technique.

E. SUMMARY OF CHAPTERS

The following chapters provide an overview of ASW operations and the simulation design model, execution, and analysis. Chapter II covers general knowledge of ASW operations. Chapter III discusses the conceptual design of the simulation program. Chapter IV gives a description of the agent and object interactions and how the user can monitor these interactions. Chapter V discusses analysis and the findings of a sample experiment. Chapter VI confirms the success of the model; suggest possible applications and expansion of the model, as well as possible future research.

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II. ANTI-SUBMARINE WARFARE NOTION

Anti-Submarine Warfare (ASW) possesses numerous peculiar concepts that must be well understood for understanding the proposed simulation. This chapter briefly surveys the ASW concept, as well as the ASW weapons, screen, and water conditions. This chapter is crucial to the understanding of the following chapters. Additional information on ASW can be found in the list of references at the end of this thesis.

A. ANTI SUBMARINE WARFARE

Anti-Submarine Warfare (ASW) is the art and science of eliminating the enemy submarines' effectiveness. There can be no ASW without submarines. Therefore, it is important to first focus on the enemy submarines.[5]

B. THE THREAT

Submarines are battle vessels that can dive and maintain a submerged position during an attack or other operations. Submarines have multiple operational capabilities and can be used for attacking land targets with long-range ballistic missiles, for damaging the enemy's cargo ships, for intelligence collection or for deploying SEALS or other special teams. Additionally, submarines can be strategically used during warfare to damage the enemy's commercial transportation lines.

Two types of submarines are used in modern day warfare: nuclear and diesel-electric. Nuclear submarines make more noise than conventional diesel-electric submarines. Nuclear submarines are larger (length 100 to 150 m, beam 11 to 20 m, drought 8 to 14 m) and tonnage (5,000 to 9,500 tons) and can operate thousands of miles away from base. They can remain submerged for more than six months. Their main power sources are nuclear reactors, which provide power allowing them to exceed 30 knots at high speed. Diesel-electric

[5] Gardner, W. Jr., 1996, *Anti-Submarine Warfare*, Brassey's Inc., p 1.

submarines, also known as “small conventional submarines”, weigh approximately 500 to 1,500 tons and are mainly for coastal operations. Their small size (length 50 to 70 m, beam 5.5 to 9 m, drought 5 to 8 m) minimizes the acoustic target echo strength (TES) signature, which, as a result, is lower than that for nuclear submarines. Conventional submarines have maximum submerged speeds of 16 to 24 knots, very low acoustic signatures, and very short endurance at maximum speed. Quite often, a conventional submarine is unable to maintain its top speed for more than 15 to 30 minutes.[6]

A diesel-electric submarine has to reach periscope/snorkeling (P/S) depth, which is 0 to 20 m below the surface, for snorkeling. It runs its diesel engines to charge its batteries, also known as snorkeling. The snort mast (snorkel), expels the exhaust gases and circulates fresh air. At the same time, messages can be relayed by coast support units. At this time, the submarine is very vulnerable, for the crew on a plane or a ship can see the snort mast, and the fumes can be detected by IR detection devices. Today’s radar has the ability to detect snorkels from a distance of a couple of thousand yards. Therefore, submariners snorkel several times a day for only short periods, and if possible only at night.

A submarine’s primary objective is to remain undetected and can be a very powerful weapon if it remains undetected. In order to remain undetected, it must be silent and submerged at a depth that minimizes detection by the ASW forces. However, a submerged submarine can be detected via acoustic sensors in two ways. First, a listening device can hear the noises emitted by the submarine. The main engine, auxiliary engines, fans, pumps, propeller, or the transmissions from the submarine’s own sonic systems can emit noise. A submarine’s propeller creates cavitations, and this formation and collapse of bubbles causes noise. Using passive devices, noise caused by a submarine can be heard. Second, a device (active sonar) can be used to transmit acoustic

[6] Armo, K. R., 2000, The relationship between a submarine’s maximum speed and its evasive capacity, M.S thesis, Naval Postgraduate School, 72 pp.

energy or waves through the water which will be reflected as they hit any object in their path. Returning pulses can be picked up by a receiver of active sonar.[7]

C. THE ENVIRONMENT

1. Weather Effects

ASW operations are sensitive to weather conditions. Turbulent waves and swells make detecting noise from a submarine more difficult. Precipitation and wind also add to background noise for the detecting sensor and mask noise from a submarine at the same bearing. Waves can also prevent visibility of the submarine mast at the same bearing. Additionally, the effectiveness of surface ship personnel is also lessened by bad weather conditions.

2. Sound Energy and Gradients

Sound does not travel in a straight line through the sea, because the sea is not homogenous. The velocity of sound varies with temperature, pressure, and salinity. These factors vary at different points and depths of the sea. With the change of velocity, the direction of the sound ray also changes, creating considerable bending effects. In general temperature is the most dominant factor in determining sound velocity, since temperature has a variable pattern. Salinity does not vary significantly and pressure increases with depth.[8]

Water temperature near the surface is usually higher than the temperature at any other depth. The sun's rays heat the surface, but because of viscosity, cannot reach a depth of more than a few hundred feet. In the summer, surface temperature is at its peak; but, in winter, the highest temperature level can be measured at a depth of 20 to 30 feet. The temperature drops sharply with depth after its peak value. This rapid decline in temperature associated with depth is called "thermocline" or "layer." The layer near the sea's surface belt is called a

[7] Hill, J. R., 1985, *Anti Submarine Warfare*, 3rd Ed. Naval Institute Press, p 39.

[8] Hill, J. R., 1985, *Anti Submarine Warfare*, 3rd Ed. Naval Institute Press, p 45.

permanent thermocline. In a classic example of a surface belt, sound can travel very far in a surface duct. Under the surface, sound rays bend downward. When the rays reach the thermocline, they bend towards the surface. At the surface, the rays bend back towards the water. Sound diminishes with distance as it encounters water molecules which absorb the sound's energy and turn the sound into heat.

In winter, water temperature is usually constant with depth, called "isothermal gradient." In that situation, sound rays do not bend, but can travel through water and reach great depths. Hull-mounted sonar is most effective in conditions of isothermal gradient. After an isothermal gradient, temperature decreases with depth. This is the main thermocline. Sound velocity also decreases, and the sound rays bend downward. Sound velocity reaches its minimum at 4,000 feet where the temperature is constant with depth, but the velocity increases with pressure. In this case, a deep sound channel is formed between the thermocline and the next increasing sound speed layer where the sound rays begin to bend upward. The sound is trapped in the sound channel and can travel long distances (see Figure 1).

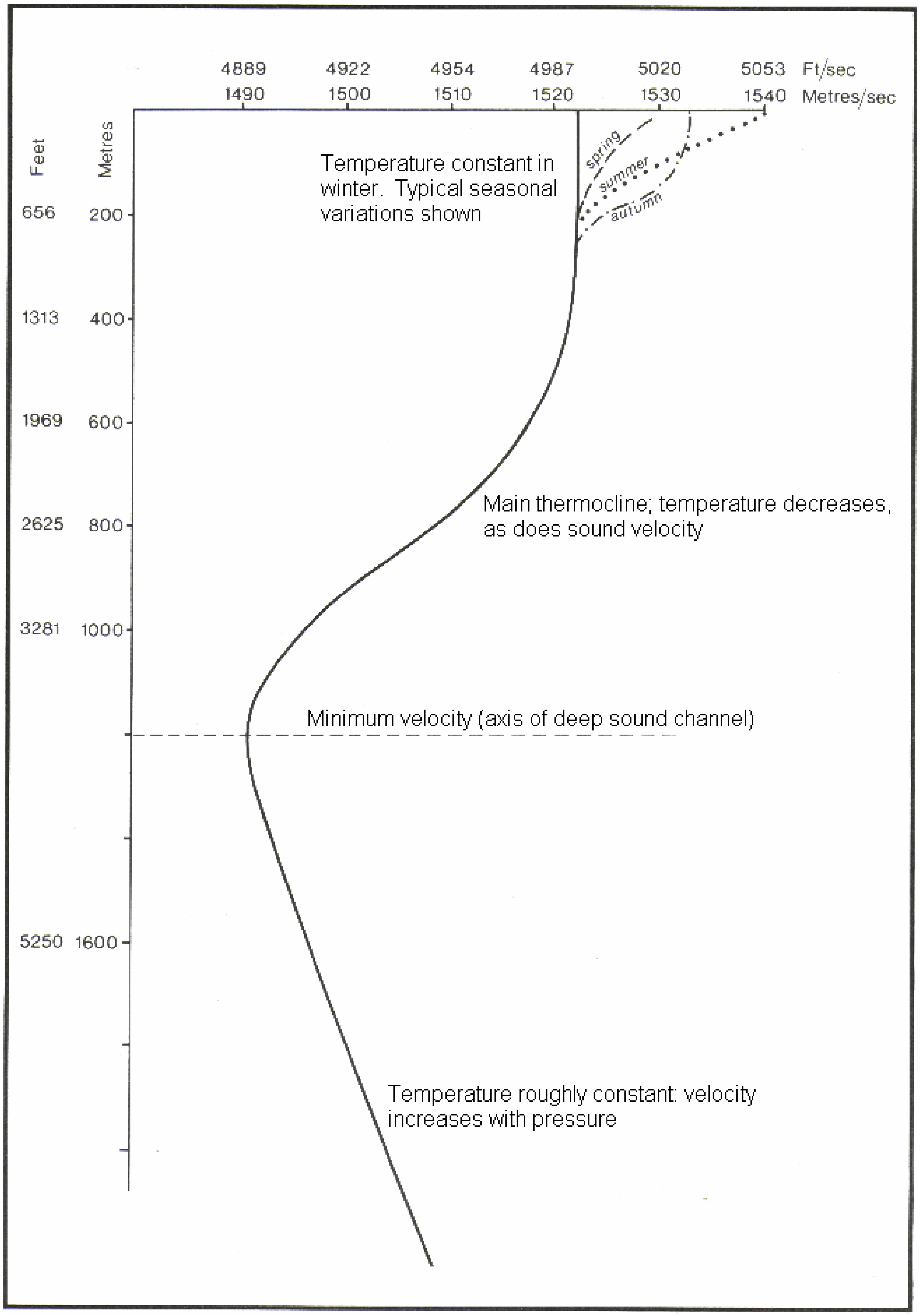

Figure 1. Variation of Sound Velocity with Depth (After:Hill,1985, 38)

During the summer in the Mediterranean, when the surface duct is warm and very shallow, there is a negative gradient below the surface duct where a sound channel exists at 1,000 feet. Active sonar beams, from hull-mounted

sonar, can reach the sound channel where they bend upward with increasing pressure and gather at the surface about 30 to 60 miles from the source as shown in Figure 2. This is known as the convergence zone (CZ).

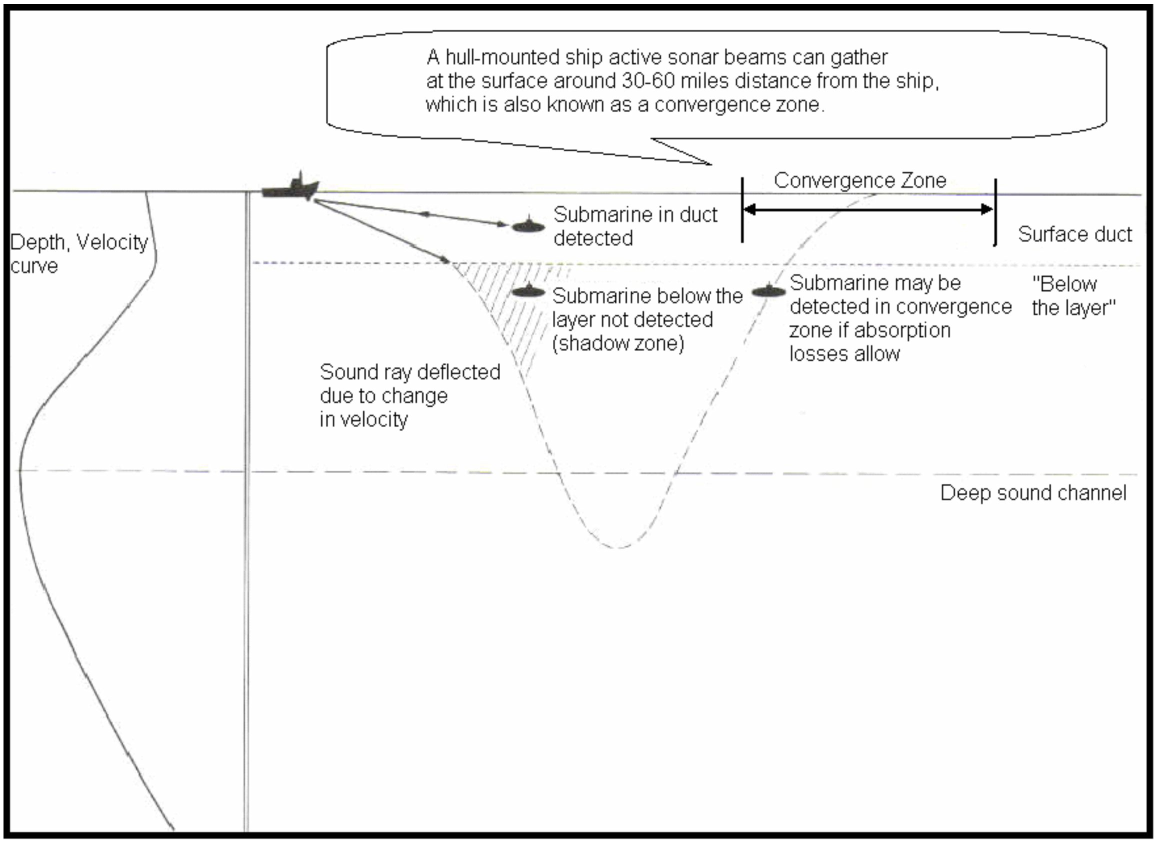

Figure 2. Formation of Shadow and Convergence Zone (After: Hill, 1985, 40)

At thermocline or layer, sound rays cannot penetrate and bend up as a result of reflection. A considerable percent of the sound energy turns into heat. Below the layer, sound rays are deflected and bend downward due to a change in their velocity. A shadow zone occurs below the layer, into which sonar rays cannot penetrate, as a result of reflection and deflection. The submarine positions itself in a shadow zone to prevent detection, as shown in Figure 3. The best approach for gaining contact with a submarine located in the shadow zone is to position the sonar below the layer. Helicopter dunking sonar or depth-variable-towed-array sonar (DTAS) are used for this purpose.

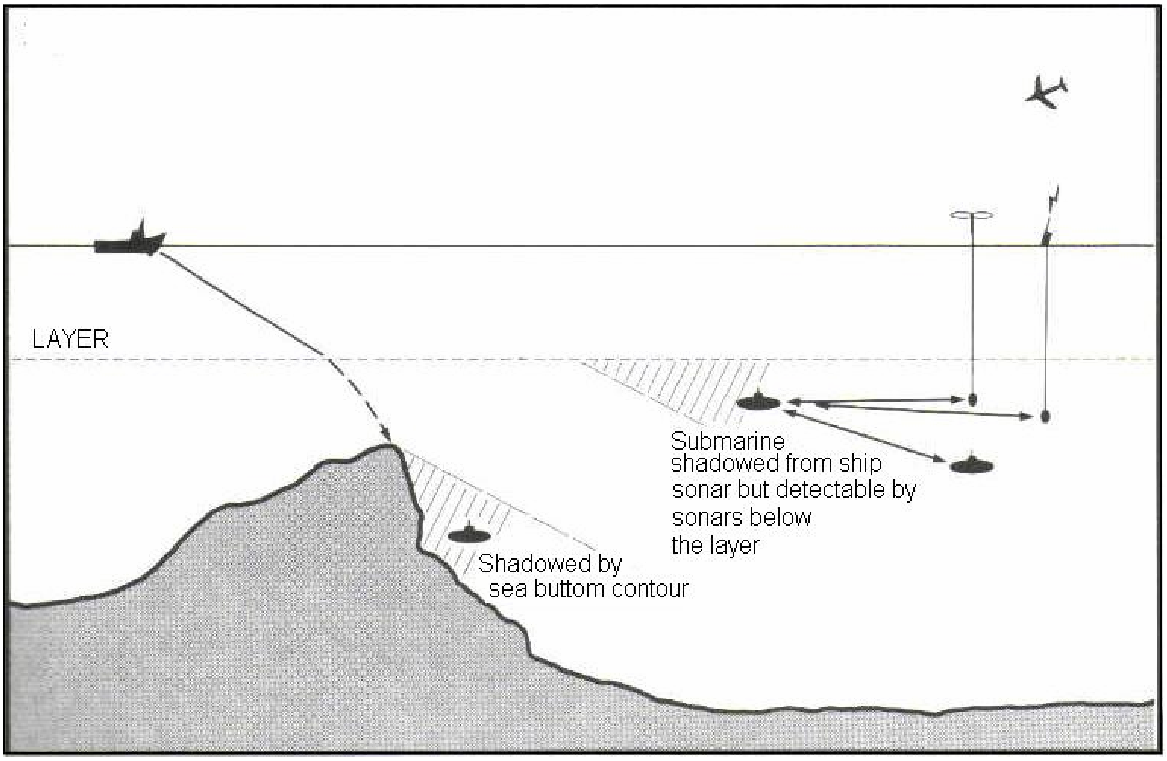

Figure 3. Bottom Effects and Sonar Below the Layer (After: Hill, 1985, 41)

3. Sonic Equipment

Active sonar for detecting sound rays needs to be reflected from the target. Propagation loss is relatively severe during the two-way trip. If a long range is needed, lower frequencies are required. The range is determined by the transmitted power. The more energy transmitted, the greater the reflected signal. The relationship between increase in power and range is not linear, but logarithmic.

Passive sonar can detect noise from sea creatures, noise from other surface ships in a battle group, and the ship's own propeller and engines. A surface ship, with towed array sonar (TAS) for passive listening, can be placed at a distance from other surface ships in the force to minimize mutual interference.

4. Non-Acoustic Detection

a. Magnetic Anomaly Detectors (MAD)

Since a submarine is made of ferrous metal, it causes a local change in the earth's magnetic field when passing through an area. The magnetic effect can be detected at distances of several hundred feet by Magnetic Anomaly Detectors (MAD). MADs are used by planes or helicopters for detection purposes.

b. Infrared (IR)

Water is circulated through the submarine's machinery to cool it. The circulated water is discharged at higher temperature. This temperature change can be detected by infrared (IR) devices. Additionally, a submarine's snort mast also provides an infrared (IR) target.

c. Turbulence

Turbulence results from the displacement of water as the submarine moves through it, and this can be noted visually.

d. Electronic Support Measure (ESM)

Radar and conventional transmissions from a submarine can be easily detected by Electronic Support Measure (ESM) devices to obtain the bearing of the submarine.[9]

e. Radar

A submarine's snort mast and attack periscope can be detected by modern radars.

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[9] Hill, p 43.

D. ASW PROCESS

Advances in technology, such as satellites, allow for more effective tracking of submarines as they transit from the base to operational areas. A satellite can monitor a submarine while it navigates on the surface during its transit. However, after submersion, a satellite cannot detect the submarine. Other means of ASW operations are required to eliminate the submarine's effectiveness in the sea.

Five phases are involved in the ASW process:

1. Detection
2. Classification
3. Localization
4. Tracking
5. Kill

1. Detection

Detection refers to a contact being made with an object, believed to be a submarine. The detection can occur through the following mediums: visual/radar, MAD, ESM devices or acoustic. A maritime patrol aircraft (MPA) can be used effectively to search an area, and patrol it for at least six hours, as determined by its fuel capacity. An MPA has several mechanisms for searching and detecting a submarine in the area. The basic means for searching is visual detection by the pilots who look for the body or mast of the submarine near the surface. A more effective way of detection is using magnetic anomaly detection (MAD). MAD is a short-range, out of water sensor that has wide coverage capability. Since MAD devices must stay relatively close to the water's surface to be effective, they can only operate from low-flying aircraft.[10] An MPA can also deploy a passive or active sonobuoy to detect the submarine and monitor its acoustic field. A sonobuoy is a cylindrical device, made of levels of hydrophones, which can be programmed to specified depths. Sonobuoys can be active and/or passive, and can be used together for greatest efficiency. Bearing information can be obtained through directional, passive sonobuoys. Non-

[10] Daniel, D. C., 1986, *Anti-Submarine Warfare and Superpower Strategic Stability*, University of Illinois Press, p 71.

directional passive sonobuoys provide contact indication only within their fields. When used in tandem sonobuoys can detect a submarine, transmit its range and bearing, or both, and provide contact indication information to a receiver on a ship or aircraft.

Ships have different types of sonar to detect submarines. Hull-mounted sonar can transmit acoustic signals. Ships can also tow a cable with sonar arrays. The depth of the sonar can be set depending on the speed of the ship and the length of the cable. Sonar can be used in passive, active, or passive and active modes. An ASW ship can carry a helicopter installed with dipping sonar. One advantage of using dipping sonar is the ability to place the sonar device under the layer through which hull-mounted sonar cannot transmit. The helicopter can operate for two to five hours depending on its type. A disadvantage of using helicopters in the ASW operation is their susceptibility to weather conditions. At sea state four, a helicopter can hardly operate in the area. Another disadvantage is that the ship has to maintain at the same speed and course as the wind while the helicopter takes off and lands.

2. Classification

Classification is making a judgment about a contact and assessing whether or not that contact is a submarine. Big sea creatures, sunken ships, and sea bottom contours can be very deceptive, since they often resemble submarine silhouettes on sonar detection. The doppler effect, which states that an approaching target will, because of its relative movement, return an echo at higher frequency is used to analyze contacts. When a target recedes, the sound waves are stretched, and cause the sound's pitch to decrease.

3. Localization

Localization is a process for obtaining an accurate position for a submarine contact.[11] The bearing and distance can be obtained through active

[11] Hill, p 48.

sonar with accuracy that depends on the device's characteristics and range. Some hull-mounted active sonar automatically focus on the bearing of the contact, instead of omni 360°. They transmit more acoustic energy through the sector. A submarine can detect the point at which the surface ship obtains an active sonar contact because transmissions from active sonar sources result in an immediate increase in acoustic energy signaling the ship that the submarine has been detected while simultaneously alerting the submarine.

4. Tracking

Tracking is a process of obtaining an estimation of a submarine's past and future movements for a fire solution. For passive devices, such as a cross bearing is required. The estimated position accuracy depends on the angle between the passive devices and the target.

5. Kill

Kill is the last phase of the ASW process. To kill a submerged submarine, a weapon needs to be placed into the water. The weapon needs to explode at a distance that is lethal to its target.

E. OPERATIONAL CONCEPTS

One of the main operations in ASW is convoy or High Value Unit (HVU), protection. As an example, merchant ships need to be protected from enemy submarines along their transport routes. The best way to protect them is to group them in a convoy. The command and control ship in a battle group or the biggest replenishment ship can be assessed as HVU units. Losing these units will cause other vessels at sea to suffer severely. ASW ships form a special shield for protection of convoys or an HVU. Most often, three to six ships with hull-mounted active sonar are positioned on the perimeter of the convoy for anti-submarine defense.

A submarine with the intent of sinking the HVU in the convoy will try to maneuver into an attack position. During an attack, the submarine increases its risk of being detected, since it breaks silence. It may decide to withhold an attack and risk the convoys reaching its destination safely. If the submarine decides to use the attack periscope or active sonar to obtain an accurate bearing and range to the target, it is subject to detection by surface ships.

An aircraft can support a battle group by searching the area of interest visually, checking for radar and visual sighting of periscopes, using its MAD, deploying and monitoring sonobuoys. Helicopters can use dipping devices at the convoy's outer perimeter. Fixed wing aircraft or helicopters can be considered mobile weapon platforms. They can be used effectively in the areas outside of the surface ships' torpedo ranges. These platforms can arrive at the identified point of contact in minutes because of their speed advantage. The time between detection of a submarine and attack is very important in minimizing a submarine's probability of escape. A torpedo in the water launched by a surface vessel or aircraft, will cause the submarine to cancel an attack, since the submarine's priority is its own survivability. The submarine will need to reposition itself for another attack or find a new fire solution.

A friendly submarine can also be used as a detection device, but its own safety is compromised when it comes to the surface to obtain relayed messages or to transmit information regarding an enemy submarines.

F. WEAPONS

When a sonar contact is classified as a submarine, a torpedo is launched to a computed future position of the submarine. The calculation of the position where the torpedo enters the water and the required course and speed for the attack platform is called fire solution problem. A light-weight torpedo can be dropped from a fixed wing aircraft or helicopter, or launched from a ship. After a modern torpedo is launched, a self-homing operation is initiated by its own machinery and propeller. The torpedoes in NATO country inventories are mostly

US origin MK44 and MK46 types. These torpedo types have been in service since the early 1950's. The MK44 type is an active homing torpedo with a maximum speed of 30 knots; the MK46 is an active/passive homing torpedo with a maximum speed of 45 knots. When an MK46 type torpedo is fired in passive mode, it will attempt to obtain a contact by acoustic energy (noise) emitted by the submarine's propellers or machinery. An active sonar pulse from the submarine will also guide the torpedo to its target. Both torpedoes' ranges are between 3,000 and 8,000 yards. An Anti-Submarine Rocket (ASROC) is a rocket that is attached to a torpedo and can propel it 10,000 yards in the air. It is very important for the torpedo to be launched close enough to the target, since the target must be located by torpedo's sensor. The torpedo will execute search patterns to maximize the probability of submarine detection (see Figure 4). It will continue its search pattern until it exhausts its fuel. Surface ships near the drop point will turn off their active sonar to avoid mutual interference.

Other types of weapons including depth charges or mortars are used against submarines. A depth-charge is a bomb which explodes at a programmed depth and can be launched via rails installed on the deck of a surface ship.

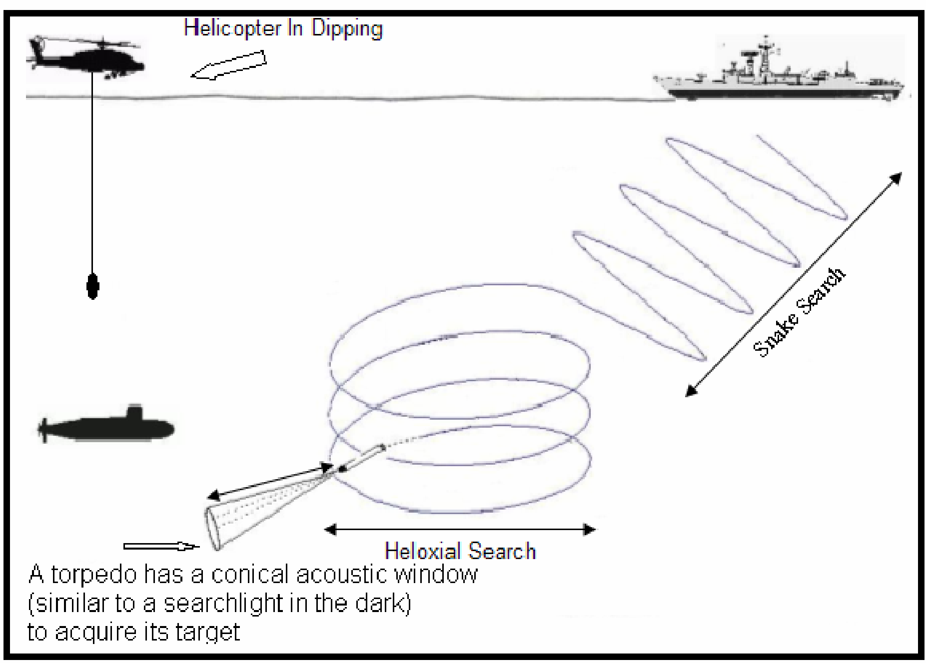

Figure 4. Active Homing Torpedo Search Pattern

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III. CONCEPTUAL DESIGN

A. ASW SIMULATION

This chapter explains the conceptual design of the Anti-Submarine Warfare screen that will be used in the simulation. A conceptual design is very important to the process of producing a software program for evaluating a specific problem. This step must be accomplished before any actual program code implementation is done, since it helps to clarify goals in the early stage of the project. The conceptual design does not have to contain detail, but must exhibit the main characteristics of the model. However, the final product is often different from the conceptual design due to various factors such as resource constraints and feedback received.

The initial conceptual design of the ASW Screen for simulation was conceived of as a final project assignment in the “Agent-Based Autonomous Behavior for Simulations” course.

B. THE PURPOSE OF THE MODEL

The purpose of the simulation model is to strategize Anti-Submarine Warfare (ASW) operations in order to protect a High Value Unit (HVU). In the simulation, the number of available surface ships with ASW capability will be between four and eight. The program will allow a diagram of surface ships protecting an HVU to be displayed on the ASW screen (see Figure 5). The command and control ship in a battle group, or the biggest replenishment ship, can also be designated as HVU unit, since losing this unit would be detrimental to the operation of other forces at sea. The surface ships are free to maneuver within their assigned sectors. The objective of the surface ships is to cover their sector as well as possible to prevent a submarine from attacking the HVU. The model will help to predict the outcomes of each maneuver by individual surface ships and how each ship contributes to the HVU’s defense.

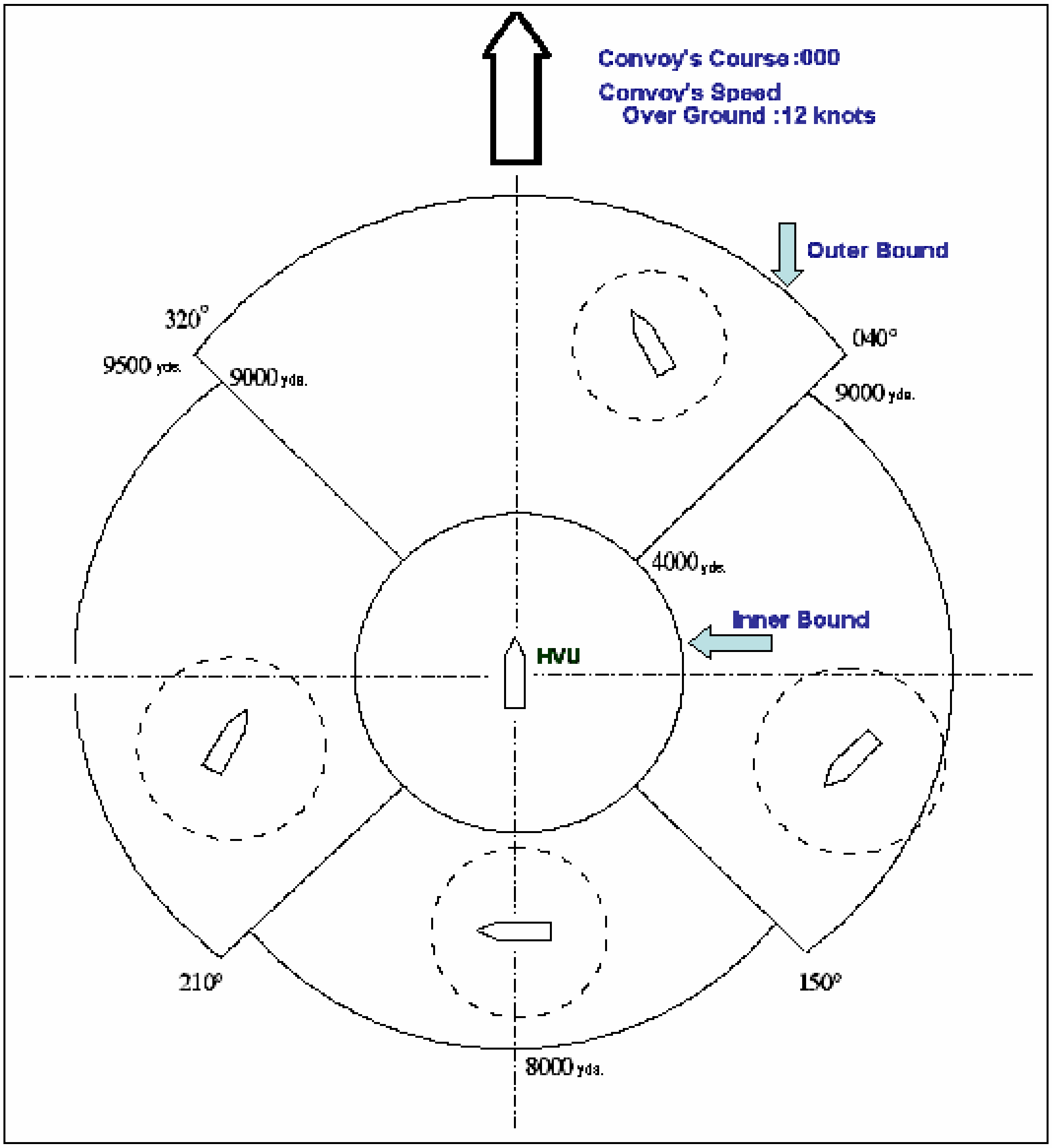

Figure 5. A Typical ASW Screen

The purpose of using the model is to provide answers to the following:

1. How a change in the convoy's speed will affect the outcome.
2. If a better measurement of effectiveness (MOE) value can be obtained if more ships are placed in the simulation.
3. If positioning a ship with towed array sonar (TAS) in front of the sector, and apart from the convoy, will be beneficial to the HVU's protection from submarines.
4. If the frontal sectors are changed: will the ASW Screen effectiveness be increased.

5. If the parameters of the inner or outer boundaries for any individual ship's sector are changed will the model's results are changed.
6. If water conditions will affect the outcome of the surface ships' effectiveness.

The model will help the user evaluate how each individual ship's maneuvering, within its sector, affects the other ships' maneuvers. The model will determine situations when gaps occur between sector borders and whether time is sufficient for a submarine to penetrate the screen. The simulation will help the user explore emerging patterns during runtime. A software laboratory will be developed where the issues mentioned above and others can be investigated to gain more insight into anti-submarine defense of an HVU.

The software will use Multi-Agent System (MAS) techniques. An agent is a computer system that is placed in a defined environment and acts autonomously within this environment.[12] Agents have their own intelligence and are able to adapt to situational changes to meet their design objectives. An agent will sense its environment and take required actions to modify that environment. In a Multi-Agent System (MAS), actions of individual agents will affect the other agents' decisions. Hence, it is very difficult to predict the outcome before running the model. MAS technique is very useful since it involves cognition and decision making to map out the complex patterns of interactions among the agents. A software laboratory using MAS techniques is capable of surprising even the designer.

C. MAS REQUIREMENTS

Every MAS involves six elements:[13]

1. Environment
2. Objects
3. Agents
4. Rules or Relationship
5. Operations and Laws.

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[12] Wooldridge, M., 2002, *Multi Agent Systems*, Wiley, p 15.

[13] Ferber, J., 1999, *Multi-Agent Systems*, Addison-Wesley Inc., p112.

1. Environment

The simulation is designed to train ASW commanders to configure the ASW screen. The simulation operates assuming, that in the scenario, a surface group travels within a defined area to defend the HVU from submarines. The convoy is positioned to maneuver within a strait with no available alternative routes due to blockage by enemy sea mines. The intelligence sources will confirm that there are one or two enemy submarines operating in the area.

The simulation focuses on a rectangular area of 35 x 50 nautical miles (NM) (see Figure 6). The convoy is programmed to bear north. The surface ships in the simulation are ASW capable and have hull-mounted sonar installed. They escort the HVU, which does not have ASW capability. Some surface ships are also carriers of ASW helicopters, and are required to stay within their assigned sectors; but are free to set their courses and speeds. The main force's initial position is at the southern edge of the ASW area.

The program's user can choose either one or two submarines for the model at the beginning of the simulation. The submarines' initial positions, speeds, and courses are unknown to the surface group. When a submarine is within a surface ship's sonar range, detection of the submarine will be determined by a probability distribution. At initialization, submarine is positioned randomly within 2/3 of the ASW area, north of the main force's location. The main purpose for positioning the submarine(s) near the center of the ASW area, instead of placing it near the initial position of the surface group is to allow sufficient time for an attack.

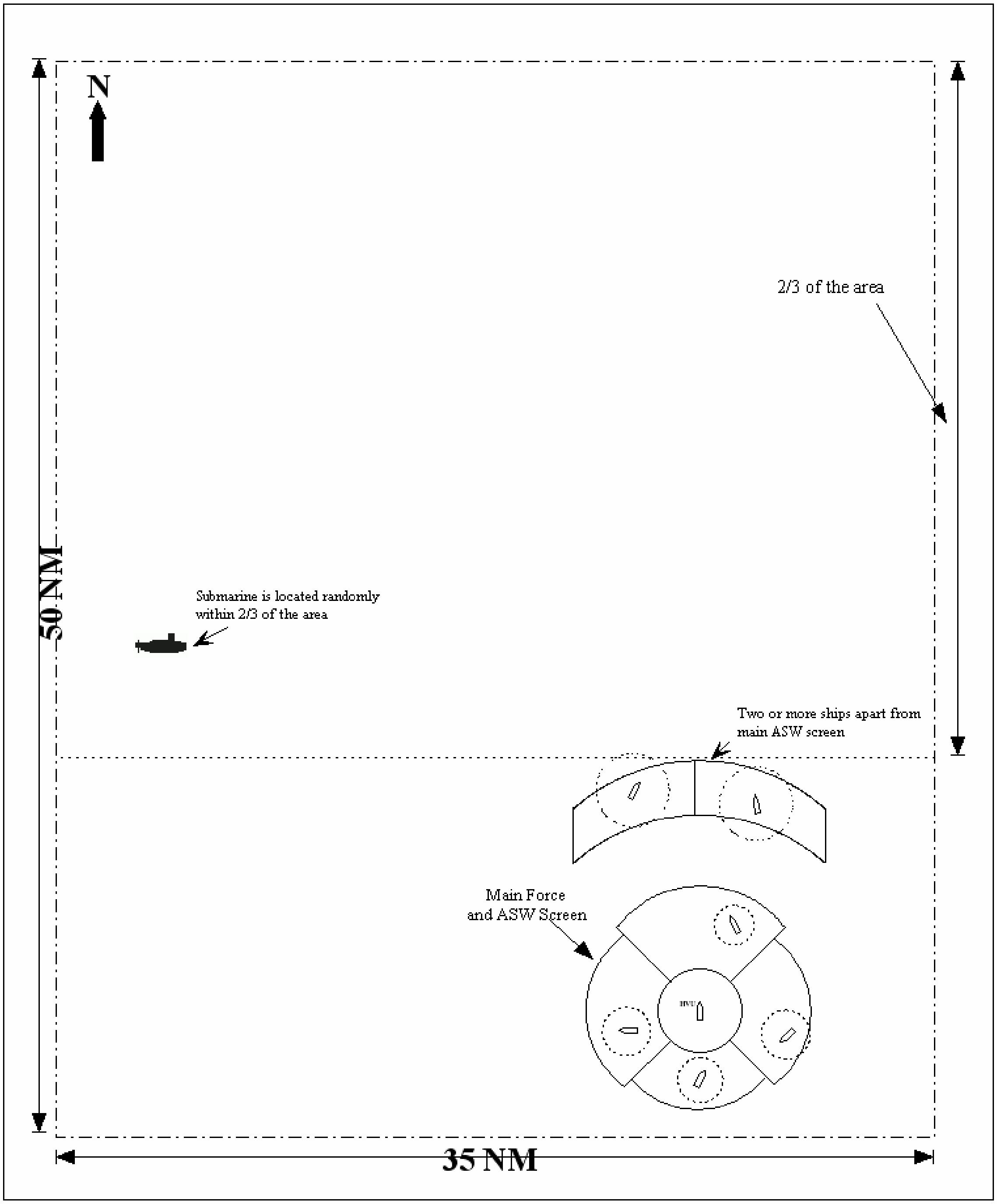


Figure 6. Operational Area (Not Drawn to Scale)

If two submarines are to be positioned within an ASW area which is divided into two equal operational areas each known as a Submarine Action Area (SAA). An SAA prevents mutual interference between submarines to ensure

their safety from friendly fire. Each submarine needs to stay within its assigned SAA. Figure 7 shows two submarines in their operational areas. The model involves only conventional diesel-electric submarines. Since the main power source for a submerged conventional submarine is battery units, the battery charge level is the most critical issue when in a submarine's operation. Speed is correlated with battery level. At high speeds, a submarine consumes more battery power. For example, in speeds between three and four knots, a submarine can operate 48 hours without snorkeling. It can maneuver at speeds between 18 and 24 knots for 72-50 minutes. Then, its batteries need recharging. However, when the submarine maneuvers at high speed; for example 22 knots for 30 minutes, its battery charge units drop 60%.

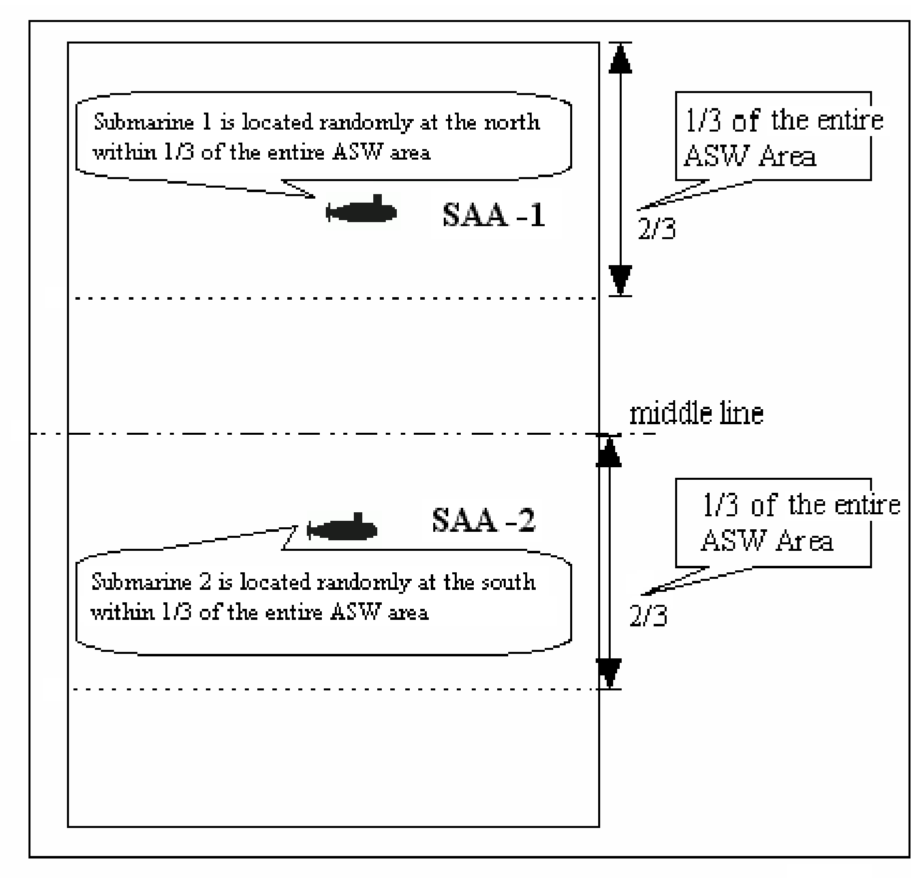


Figure 7. Locating Two Submarines in the ASW Area (Not Drawn to Scale)

The main force's speed is dependent on the HVU's speed because the surface ships needs to remain within their defined sectors, determined by the HVU's position (see Figure 5). Furthermore, escort ships have a speed and maneuver ability advantage as compared to the HVU. During runtime, the program's user can change the main force's course between 0° - 45° at a time. The default course of the surface group is 000°. The user is also able to choose a zigzag pattern. The changes in a surface ship's course, in a zigzag pattern, within specified intervals are shown in Figure 8. The ship maneuvers in a zigzag pattern to complicate the submarine's torpedo firing calculation, making it more time consuming and difficult to lock onto the ship's position. The user is able to enter the zigzag pattern at the beginning of the simulation. The main force's (HVU) speed is between 10-14 knots. Escort ships are able to maneuver two knots above the HVU's speed to their maximum speed.

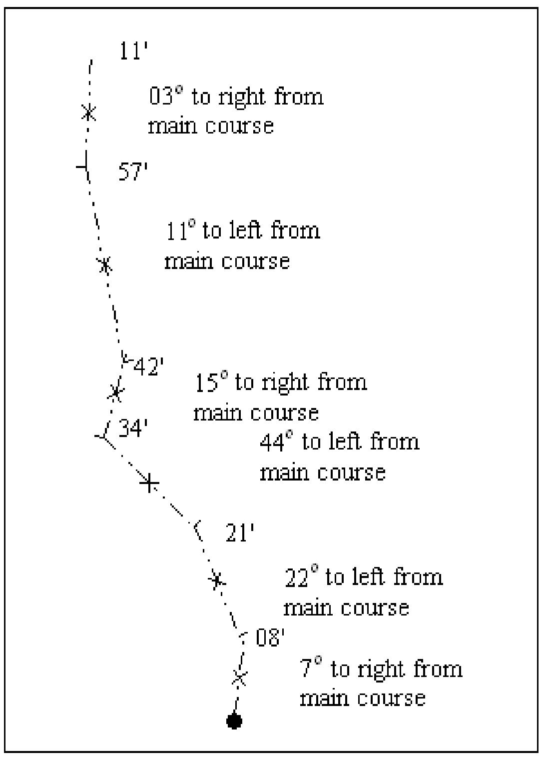


Figure 8. Example of a Zigzag Pattern for the Main Force (Not Drawn to Scale)

Since a conventional submarine is very quiet, the surface ship's sonar personnel do not detect the submarine when using a hull-mounted sonar in

passive mode. Thus, the surface group uses sonar in active mode to detect the submarine. The program user may also choose a sonar policy which forces surface ships to turn off their sonar for specific time intervals. This kind of sonar policy can prevent mutual interference from hull-mounted sonar. A submarine can detect fewer acoustic clues while a restrictive sonar policy is in progress. See Table 1 for an example of a sonar policy.

Ship Name	Time when sonar is ON starting at the top of the hour for each hour (min)	Total interval time when sonar is ON for each hour (min)
TCG YILDIRIM - TCG TURGUTREIS	*10-20*	*10*
TCG SALIHREIS - TCG KEMALREIS	*20-40*	*20*
TCG MUAVENET - TCG KARADENIZ	*40-10*	*30*

Table 1. A Sonar Policy Example

There are two sonar types in the model medium and long range. An active sonar device range depends on its power. The more acoustic energy a sonar device transmits into the water, the better the range. Maximum range for both sonar types is determined by normal distribution. Table 2 shows minimum and maximum range values for both sonar types. If desired, the user can elect to input minimum and maximum sonar ranges for both sonar types at the beginning of the simulation.

Sonar Type	Range Intervals (In Yards)	
	Min	Max
Medium Range Sonar	3,000	7,000
Long Range Sonar	4,500	9,800

Table 2. Sonar Ranges For Hull-Mounted Sonar

If the user does not specify sonar ranges, the program will calculate the maximum sonar ranges for both types, according to normal distribution within the given mean and standard deviations. See Figure 9 for an example of the parameters and normal distribution graphs.

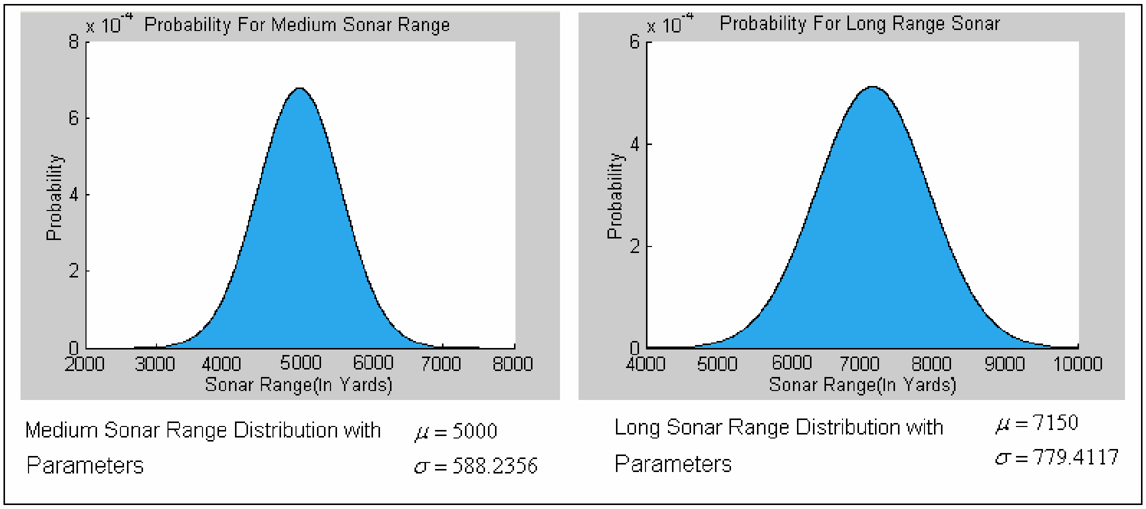


Figure 9. Sonar Range Distributions for Medium and Long Range Sonar Types

In the program, the submarine operates within periscope/snorkel (P/S) depth of between 10 to 15 meters. The simulation provide water conditions of isothermal gradient, usually seen in winter, when there are no layers, and sonar rays can reach a depth of 250 meters. The simulation does not operate when there is a layer (thermocline), since the sonar rays cannot penetrate or are reflected from the layer. Submarines located under the layer cannot be detected by hull-mounted sonar.

During the simulation, when the submarine is within the ship's sonar range, it will be detected and destroyed immediately. In addition, once the submarine is detected, it is not able to attack. The submarine will plan a torpedo attack to sink the HVU. A successful torpedo attack will be determined by a stochastic process. Table 3 shows the probabilities for a successful attack according to the range. In the model, a torpedo fired from the submarine targeting surface ships should not be considered a particular type. A modern

conventional submarine can have different types of torpedoes loaded in its torpedo tubes. Therefore, the probabilities used in the program for the success of an attack have been gathered from different NATO torpedo characteristics and abilities with ASW experts' judgments. (Since firing a torpedo is complex-the sample size for tries is small-the probabilities are far from a validation.)

For example, if a Type 209 submarine fires a torpedo at a distance of 11,000 yards; its probability of success is 0.60. The probability of success in the program refers to probability of kill. The program will calculate a uniform random number between zero and one. If the number is less or equal to 0.60, the attack is considered successful.

Distance From HVU (In Yards)	Probability of A Successful Attack
0-7,000	0.95
7,000-10,000	0.77
10,000-12,000	0.60
12,000-14,000	0.48
14,000-15,000	0.24
>15,000	0.003

Table 3. Probabilities of Successful Attack Based on Distance From an HVU

The submarine is free to attack at anytime within its Submarine Action Area (SAA), unless its battery level drops to a level insufficient for an attack. It remains submerged during the simulation. Once it comes to the surface, the submarine can be detected by the ship's radar, regardless of its distance from the ship. The submarine has to maintain the same speed and course during the two minutes prior to an attack. This is the theoretical minimum time needed for the firing solution.

The submarine's position is known by the battle group immediately after it fires a torpedo. The closest ship will move toward the submarine's last known position to make contact. At the same time, the submarine will move away from the surface group at maximum speed to avoid precisely located by surface ships. In the simulation, the surface ships' weapon ranges are greater than their sensor ranges. When a ship has localized and tracked a submarine, the submarine is destroyed immediately.

During the simulation, the submarine uses only its passive sonar in order to obtain the ship's location, and never transmits an active sonar pulse. The submarine's passive sonar range is 50,000 yards (half the height of the ASW area. A submarine's systems can detect a ship's speed and course within its sonar range when a ship's sonar is in active mode. If the surface ship's sensor is in passive mode, or if its sonar is off, the submarine can still detect the ship within 6,000 yards because the submarine will be able to hear the noise caused by the surface ship's machinery or propulsion.

2. System Objects

a. Rectangular Area Object

The ASW area is 35 x 50 nautical miles (NM). The information concerning all the ships as well as the submarines, such as the position, speed, course, and sonar situation is stored in the rectangular area object. The program obtains the information concerning the ASW screen and draws the sector lines illustrating inner and outer bounds as shown in Figure 5. The ships will be drawn within their sectors and their sonar coverage will be represented by a red circle.

b. ASW Screen Object

The ASW screen object stores the information of the sector bearings and inner-outer ranges as shown in Table 4.

Sector Number	Sector Bearings (In Degrees)	Inner-Outer Sector Ranges (In Yards)
1	320-040	4,000-9,500
2	040-150	4,000-9,000
3	150-210	4,000-8,000
4	210-320	4,000-9,000

Table 4. Sector Information

At the start of the simulation, the user is required to input the number of sectors, the sector bearings, and the inner-outer ranges. The program warns the user if the inner sector boundaries do not add to 360° or if a sector begins within another sector's bearing boundaries. In addition, the user inputs the name of the ships assigned to the sectors. The outer sectors are not required to cover 360°, but outer sectors are expected to start at least from the distance where the inner sector ends.

c. Sector Objects

Every sector has a unique identification number between one and the total number of ships. Beside its identification number, the sector has the beginning and ending bearings and beginning and ending ranges. It has a string value for storing the name of the ship assigned to the sector.

The HVU is located at the center of the ASW screen. A sector is drawn on the computer screen using the x-y values of all vertices (see Figure 10).

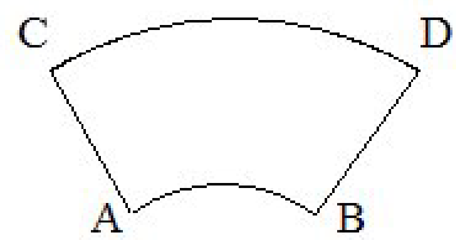


Figure 10. The Frontal Sector and its Vertices

The following is an example of the calculation of the x-y values:

The HVU is located at point (200,500), main course is 000°

Sector bearing values are between 320°-040°. Further range values are between 4,000-9,000 yards.

One yard is represented by one pixel on the computer screen

$$A_x = 200 + \frac{4,000}{100} \times \sin 320 = 174$$

$$A_y = 500 - \frac{4,000}{100} \times \cos 320 = 469$$

The x-y values for the other three points can be computed in a similar manner.

In the next example, the same values are used except than the main course is 030°. The calculation for point A on the computer screen:

$$320 + 30 = 350 \qquad A_x = 200 + \frac{4,000}{100} \times \sin 350 = 193$$

$$040 + 30 = 070 \qquad A_y = 500 - \frac{4,000}{100} \times \cos 350 = 461$$

d. Referee Object

A referee object decides the detection and attack results. This object retrieves the surface ship's position, its sonar status, and also the submarine's position. For every time step, a calculation is computed to determine whether a submarine is detected within the surface ship's sonar ranges. When a property change for the detection of surface ship occurs

depending on its sonar status, the referee passes along the bearing, distance, speed, and course of the surface ship to the submarine. The referee decides whether a submarine torpedo attack is successful or not according to stochastic processes depending on the distance from the HVU.

e. Convoy Object

A convoy consists of the HVU and the escorting ships. The HVU's location is calculated with a given speed and time by the following equations:

$$X = X_0 + v_t$$

$$Y = Y_0 + v_t$$

For example, if the HVU's initial position is (200,500) with a course of 030° and speed of 14 knots, the next position after Δt is calculated below. In this example, delta time represents one time step which is 30 seconds.

$$V = 14 \text{ knots } = 7.2 \text{ m/s} \Rightarrow 223.6 \text{ ft/s} = 7.9 \text{ yards/s}$$

$$x = 200 + \frac{v \times \sin 30 \times 30}{118.75} = 201$$

$$y = 500 + \frac{v \times \cos 30 \times 30}{204.46} = 498$$

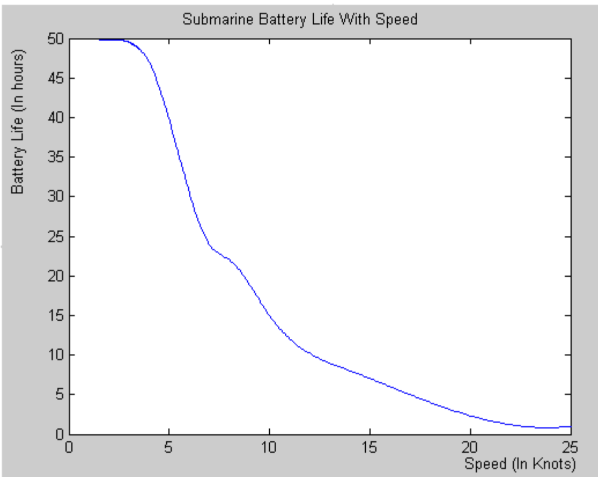
The x-y calculated here represents the new position of the HVU after one time step.

f. Sonar Object

Sonar ranges, depending on the type of sonar, are determined by normal distribution. Table 2 shows the minimum and maximum ranges for both sonar types. The initial sonar ranges are computed using the parameters input by the user or with the default maximum and minimum numbers (see Table 2), at the beginning of the simulation. After sonar ranges are determined by the program, they remain constant and cannot be changed during runtime.

g. Submarine Battery Object

The submarine battery object stores information on the submarine's battery charge level. For every time step, the battery charge level is updated. See Figure 11 and Table 5 for submarine battery endurance levels for various speeds.



Machinery Power	Speed (In Knots)	Battery Life (In Hours)
1/8	3	48.26
1/4	8	21.90
1/2	12	10.03
3/4	17	4.6
7/8	22	1.18

Figure 11. Submarine Battery Endurance Graphs

Speed (In Knots)	3	4	5	6	7	8	9	10	11	12	13
Battery Life (In Hours)	48.28	46.44	39.34	30.65	23.55	21.90	18.81	14.60	12.26	10.3	9.07
Speed (In Knots)	14	15	16	17	18	19	20	21	22	23	24
Battery Life (In Hours)	7.76	6.97	5.92	4.60	4.07	3.2	2.23	1.49	1.18	0.83	0.65

Table 5. Submarine Battery Endurance Within Various Speeds

If a submarine with 90% battery capacity level is trying to gain a firing position on a main force traveling at 14 knots, it needs to run at 17 knots for 30 minutes. If running at a speed of 17 knots, the battery can last for 4.6 hours. At the end of 30 minutes, the submarine has used 50% more of its beginning battery level. The new battery level is then 40%.

h. *Manager Object*

The manager object positions the ships at the center of their sectors and the submarine, randomly, within its SAA at the start of the simulation. This object checks or zigzag patterns and triggers he HVU for a course change when necessary. If an interval sonar policy is in progress, the manager orders he ship to change its sonar status to parallel the sonar policy.

i. *Simulation Time Object*

The simulation time (SimTime) object checks the system time and synchronously updates elapsed time with system time. The simulation terminates when the main force has exited the ASW area at its north edge or ten minutes after a successful attack.

j *Data Collector Object*

A data collector object will retrieves the information required for analysis (see Figure 12 for an example of data collector fields).

Convoy's Speed
Sonar Policy
Of Submarines
of Successful Attacks
# of Unsuccessful Attacks
# of Ships
Medium Range Sonar Range
Long Range Sonar Range
# of Ships in the Inner Screen
# of Ships in the Outer Screen
Screen Information
Simulation Total Time
Submarine Battery Level At Attack
Submarine Battery Level After Attack
Submarine Batttery Level At Finish
Submarine Survival

Figure 12. Data Collector Object Fields

3. Agents

This model is suitable for a MAS laboratory. Because the actions of ships and submarines are affected by the environment and in turn the environment is shaped by the reactions or actions of the surface ships and submarines.

a. Surface Ships

Each of the surface ships is an agent that can freely choose and act autonomously. The ships can choose their speeds and courses, but they must stay in their assigned sectors. The ships try to cover the sector as well as possible, while remaining within it. Since a ship's sensor coverage is relatively

small in relation to the sector area, it must find an appropriate search pattern for better coverage. If the ship is to remain at a particular area of the sector for a long period of time, the submarine is able to penetrate the gaps caused by insufficient coverage. On the other hand, the submarine needs some time to position itself in a good location for a torpedo attack. In addition, the submarine tries to gain a firing position at minimum speed.

The ship's movement pattern is unknown to the submarine unless the ship exhibits a repeated pattern. After some time, the submarine can comprehend the ship's search pattern and move to the optimum position for an attack.

During the simulation, the ships are able to choose their own preferences from a list. One of the preferences is to divide the sector into four quadrants and to visit each of the quadrants to a specified time limit. Figure 13 shows how a sector can be divided into four quadrants.

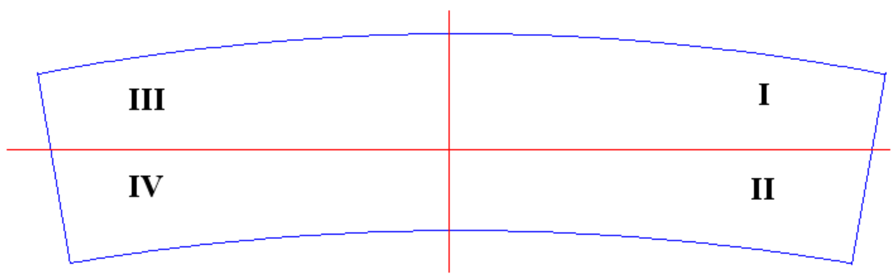


Figure 13. Dividing a Sector into Four Quadrants

The ship chooses the quadrants randomly. The model draws a random number between one and four with uniform distribution. Next, the ships determine the number of legs and time intervals for the movement according to uniform distribution. The legs are between two and four and the time intervals are between six and ten minutes. For example, the ship moves into quadrant II and executes two legs with the total movement lasting nine minutes. It then heads to the edge of the quadrant. This is point A shown in Figure 14. Since the ASW

screen is dynamic and moves in accordance with the HVU's course and speed, the ship calculates point A; where point A will be in nine minutes and bends for this location.

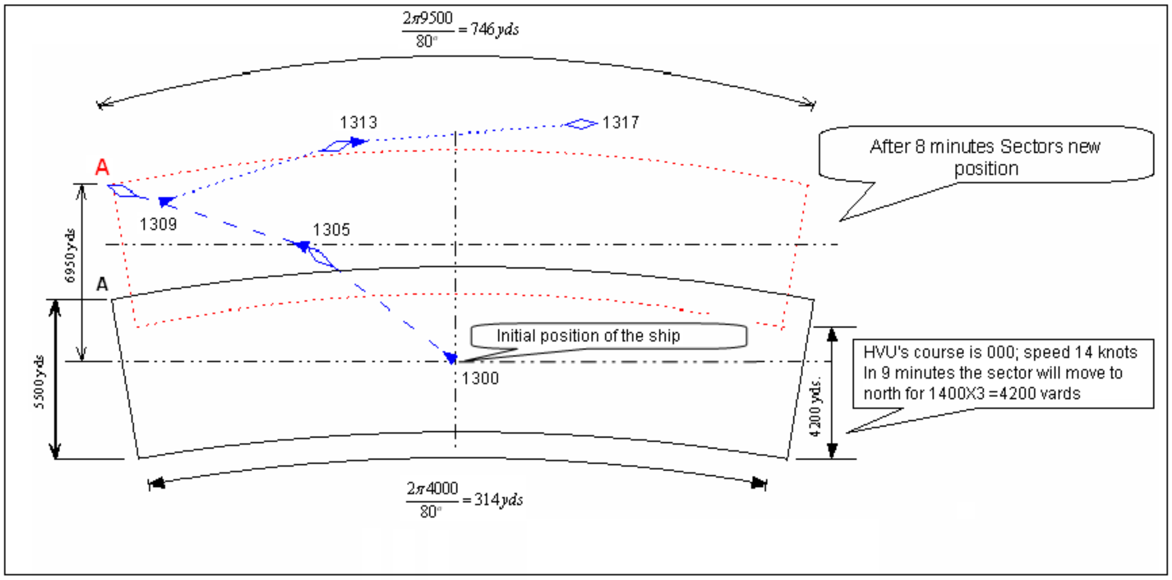


Figure 14. Ship's Search Pattern: Visiting Each Quadrant in a Sequence (Not Drawn to Scale)

An easy way to calculate the distance a vessel moves at sea is to use the "Three-Minute Rule." To compute the distance using the three-minute rule, one takes a unit's speed in knots and adds two zeroes to the speed. This is how far the vessel travels in three minutes. For example, a vessel moving at a speed of 20 knots can travel 2,000 yards within three minutes. The ship moves 666.67 yards in one minute and 6,000 yards in nine minutes at a speed of 20 knots. If the HVU's speed is 14 knots, then the ship moves six knots faster. The ship gains 1,800 yards from its initial position relative to the screen. After nine minutes it chooses the quadrant, number of legs, and time interval for the next session (see Figure14). The pattern is quite complex and is very hard for the submarine to comprehend. The pattern can be developed using a rule, stating that from top of the hour the ship visits the frontal quadrants (I or II) four times, then the rear quadrants (III or IV) , which is determined by random distribution.

Another preference can be a variant of the first, where there is cooperation between neighboring ships. The ships cover the same quadrants in their sectors, which may overlap into the sector areas covered by neighboring ships. Obviously, the ships benefit from the coverage by neighboring ships.

A ship discards a preference in order to find a better search pattern for sensor coverage. The criterion for discard is the area of the ship's sensor coverage during 40 minutes. If the preference cannot provide a coverage criterion above the threshold value, the preference is discarded.

The ships do not have knowledge of the exact number of submarines in the ASW area. The program continues after the first detection. The simulation ends only when there are two detections.

The ship picks the preference and calculates the speed requirement and course for the preference and then update the position. It reports the new updated positions for every time step. The sector is divided into square grids for sensor coverage calculation (see Figure15).

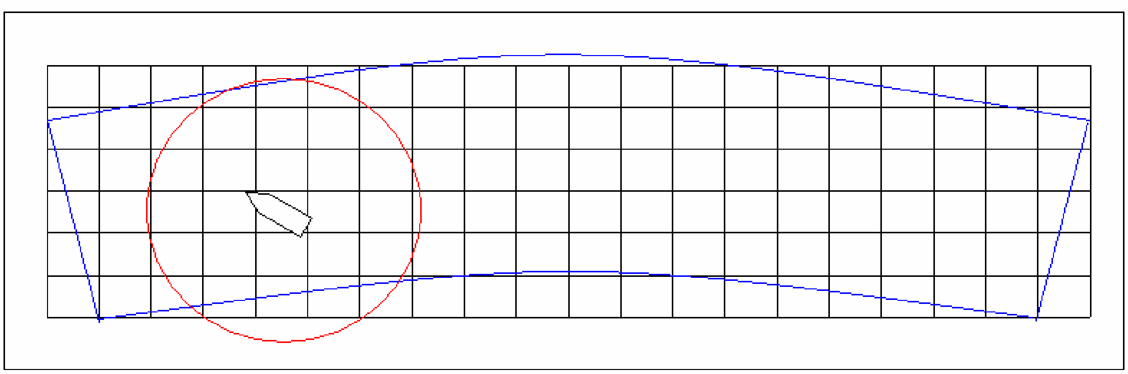


Figure 15. Dividing a Sector into Square Grids

Each grid stores an integer value, either one or zero, and the value is initialized at zero at the start of the preference. During the session, if the ship's sensor covers the grid, the grid's value is changed to one; otherwise, it remains

as zero. After 40 minutes has elapsed, the program counts the grids valued at one or the grids covered by the ship's sensor. The effectiveness function for coverage is:

$$\frac{\#\, grids\ covered}{\#\, total\ grids\ in\ the\ sector}$$

If the number returned from the effectiveness function is below the threshold value, the existing preference is discarded and the ship chooses another preference. At the start of a new preference, all the grid values is initialized to zero again. A grid is considered covered if the grid's center is within the ship's sensor range. The ship checks the distance between its location and the grid's center location. If it is less than the sensor range, the grid's value is set to one. The model only checks the grids which have not yet been covered.

b. Submarine

The submarine's initial position is a random location within the SAA. The referee object provides information on any ship within its passive sonar range. When a submarine has made a contact, it is able to get the bearing, distance, course, and speed of the target ship. Some error is expected to occur depending on distance.

The submarine tries to comprehend the location of the HVU. Since an HVU is not an ASW force, it does not have acoustic sensors. A submarine cannot obtain contact with the HVU from long distances due to the fact that it must calculate the center of the screen and assume that to be the HVU's location. The submarine takes the average of the x and y coordinates of the ships and moves to the west or east through the convoy location. It finds a rendezvous point at the relative bearing of 045 or 315, at a 10,000 yard distance from the center of the screen (See Figure 16). It calculates the required speed and course to the rendezvous point. Since the surface group can execute a zigzag pattern, the submarine needs to update the rendezvous point, calculation, required course, and speed in every simulation time step. At the rendezvous

point, the submarine checks the other ships' distances. If the distances from the ships are more than 9,500 yards and the ships are not moving towards the submarine, it then advances towards the HVU in order to increase its probability of a successful attack. If the distance for ships becomes less than 9,500 yards, the submarine decides whether or not to cancel the attack. When such a decision must be considered, if the submarine is at the same course for between one to two minutes, a random number between zero and one in uniform distribution will be drawn for a decision. If the drawn number is between 0.0 and 0.7, the submarine fires the torpedo; if not, it cancels the attack. The submarine can also change its course by reversing and moving away from surface ships. The submarine then increases its speed to 22 knots for 15 minutes or until it is 17,000 yards away from the nearest ship.

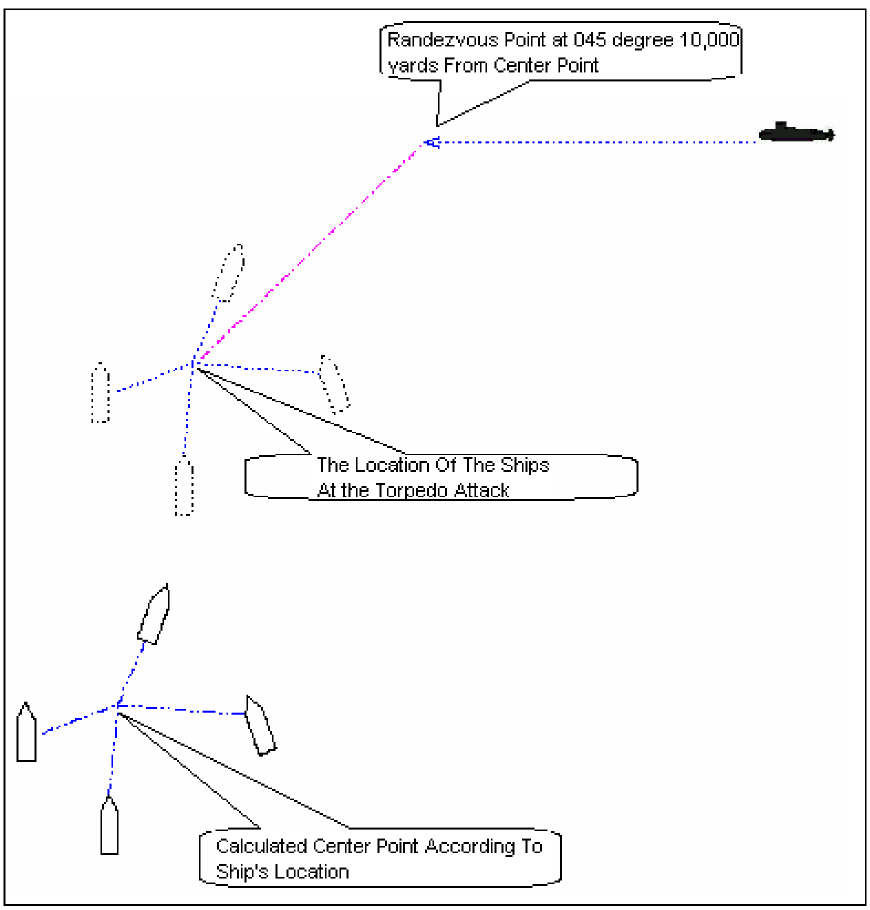


Figure 16. Submarine Movements Before An Attack

The referee object decides on the ships' detection of the submarine. At the time of the attack, the submarine's position is known to the surface group. The referee object also determines whether the torpedo attack is successful or not. If the attack is unsuccessful, or if the submarine does not have a chance to attack, it bears north at a speed of 16 knots. Then the submarine calculates the rendezvous point at 045° or 315°, 10,000 away from the center point. (The battery charge capacity must be more than 40% at attack time.) The submarine then moves to the rendezvous point at a speed determined considering the time the convoy is expected to reach a position of 225° or 135°, 10,000 yards from the rendezvous point. Then the submarine continues with the same attack procedure outlined.

The submarine attempts to attack, unceasingly, until its battery charge level is less than 40% or the convoy is leaving its SAA.

4. Relationships

a. Roles

The ships are trying to find a good search pattern with which to cover their area. They can change their preferences if the criteria for coverage are not met. The submarine attempts to attack the HVU while maintaining its own survivability option.

b. Goals

The goal of the program is to find an optimum screen configuration for protecting the HVU. The configuration's effectiveness can be measured by the number of the times the HVU reaches its destination safely. During the program's operation surface ships find their preferences for optimum coverage of their sector.

The submarine tries to attack the HVU and raise the probability of success by advancing towards its target, while it considers its ability to survive

counterattacks. The submarine cancels an attack if it determines that its current location is unsafe. At the end of the simulation, the user obtains the optimum design based on how many attempts to transit the region for the given convoy speeds and water conditions.

5. Requirements

The surface ships need to use sonar in active mode to detect a submarine. At the beginning of the simulation, the submarine position is unknown to the surface ships. The referee object notifies the surface ships of a detection. Upon detection, the submarine is destroyed immediately. After an attack, the submarine's position is known to the surface ships and the referee object decides the success of the attack and informs both the surface ships and the submarine(s). The nearest surface ship approaches the submarine's last known position in order to detect the submarine; however, the ship must stay within its sector. The program ends ten minutes after a successful attack. A final determination of the submarine's status is made by the referee object during this ten minute period.

6. Operations and Processes

The program user inputs the number of ships and submarines and the sector information when the simulation starts. The manager object randomly places the submarine within the SAA. First, the model decides the sonar ranges with normal distribution, and then it draws the screen and places the ships at the center of their sectors. The manager object retrieves the zigzag pattern and sonar policy. The ships choose their preferences. The ships report their new positions to the referee object and the referee object checks for mutual detection by surface ships and submarine. Then, the referee object checks the surface ships' sonar status. Afterwards, the sector objects update their location with the convoy's speed and courses. The submarine needs to report its updated position to the manager for every simulation time step. The grid objects' status also is updated.

The manager object checks the ships' sonar status and triggers them to change their sonar status to either ON or OFF according to the chosen sonar policy. Similarly, the HVU will be forced to alter its course according to the zigzag pattern.

When an attack occurs, the referee object determines whether it is successful or not and triggers the nearest ship to move to the submarine's last position. When an attack occurs, the data collector object obtains the results of the attack as well as the submarine battery's charge capacity. The data collector object also retrieves information from the objects such as the convoy's speed, sonar policy, and number of submarines.

The program terminates either when all the submarines in the simulation are destroyed, or when the convoy leaves the rectangular area, or ten minutes after a successful attack. At the end of the simulation, the statistical data is shown on a frame. If the program user runs the model with the same input parameters more than once, the system initializes the parameters automatically.

D. SUMMARY OF LAWS

The rules of the model include:

- The submarine's position is unknown to surface ships in the beginning.
- The ships are free to choose their speeds in their sectors (zero to max speed), but they must stay within their sectors.
- The main force will bear north.
- When the sonar ranges are initialized, they cannot be changed during the runtime.
- When there is detection, the submarine will be destroyed immediately.
- The referee object will decide whether the attack is successful or not.
- At the time of the attack, the submarine's position will be known to the surface ships and the nearest surface ship will move as close as possible to this position.

- The ships choose their preferences randomly and discard the preferences below the required thresholds.
- The submarine continues its attacks unless its battery charge level is less than 40% or until the surface group leaves its SAA. (Since a conventional submarine needs to come to periscope/snorkel depth to recharge its batteries, the batteries can not be recharged during the simulation.)
- The simulation ends when all the submarines are destroyed. If there is a successful attack, the simulation will end ten minutes after that attack.

E. HUMAN INTERFACE

A human interface allows the user to communicate with the computer program. The human interface in the simulation allows the user to input the parameters. The following are frames showing the human interface:

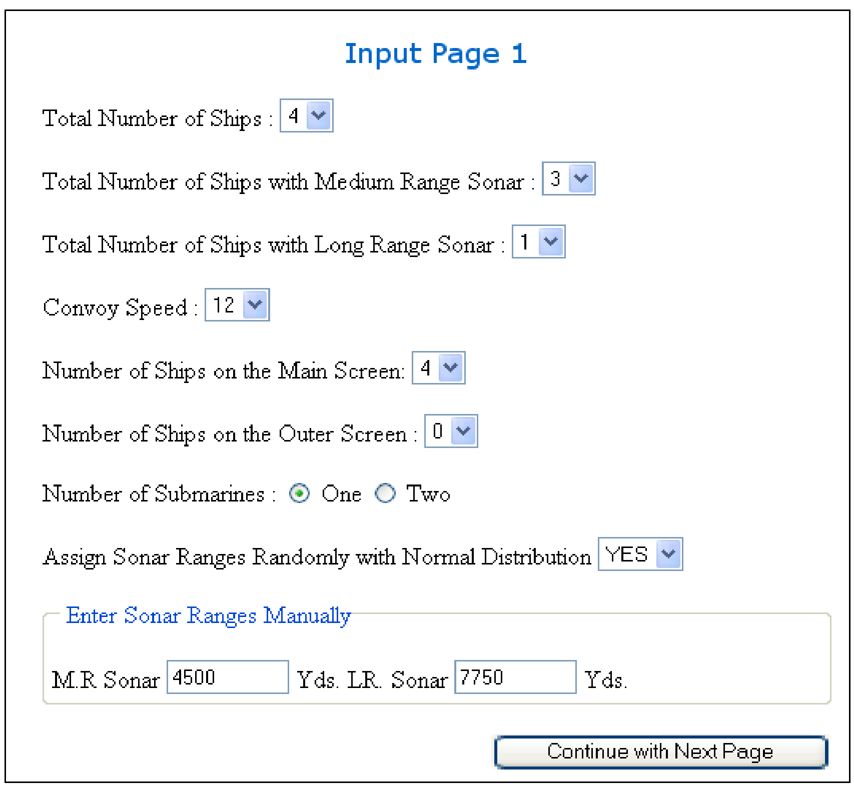
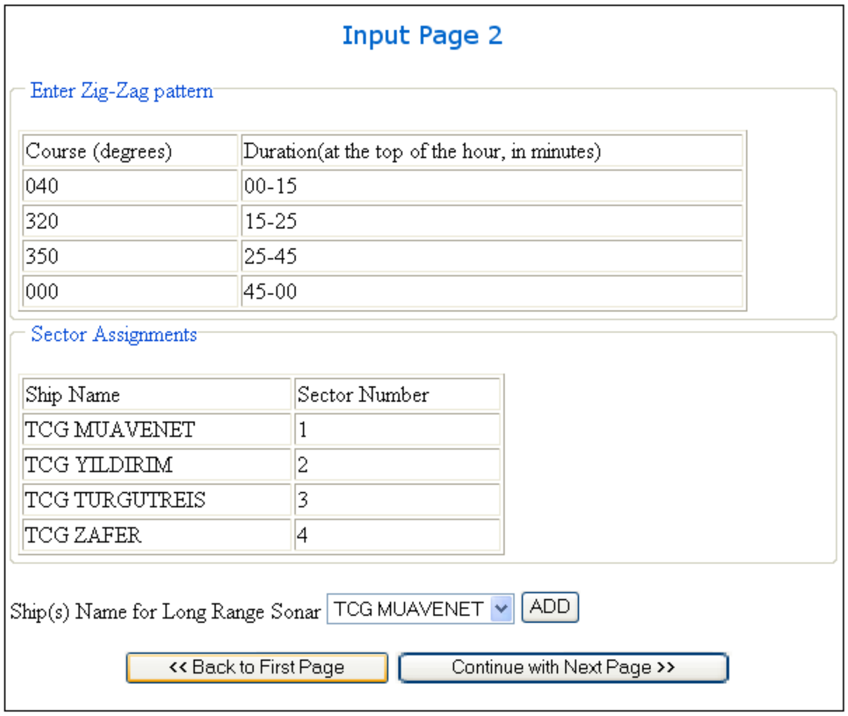


Figure 17. Input Page 1



Input Page 2

Enter Zig-Zag pattern

Course (degrees)	Duration(at the top of the hour, in minutes)
040	00-15
320	15-25
350	25-45
000	45-00

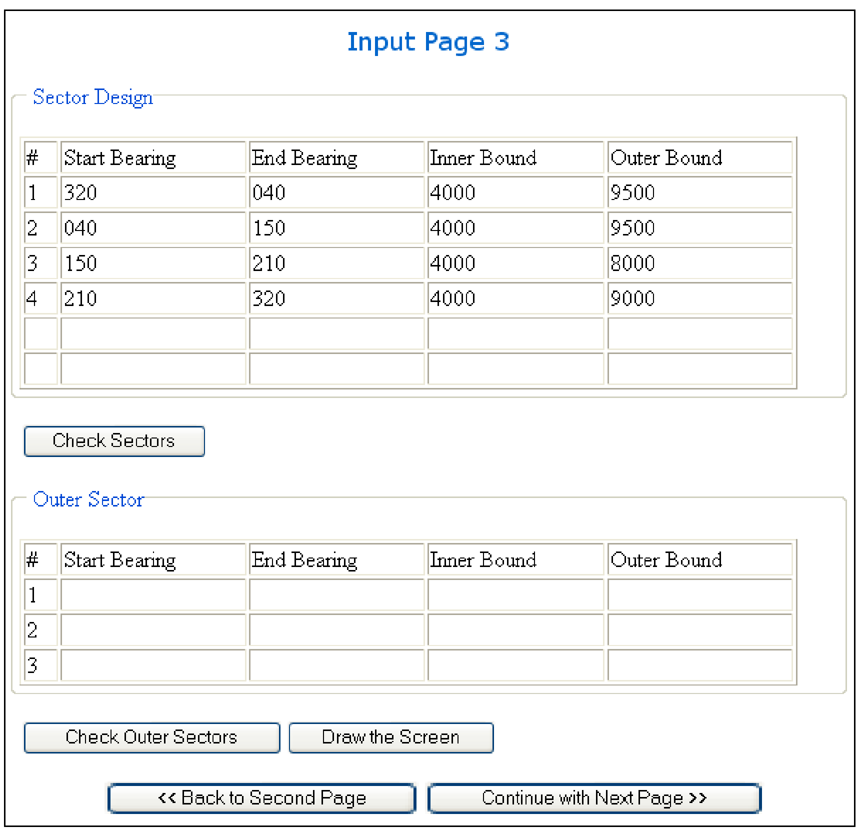
Sector Assignments

Ship Name	Sector Number
TCG MUAVENET	1
TCG YILDIRIM	2
TCG TURGUTREIS	3
TCG ZAFER	4

Ship(s) Name for Long Range Sonar TCG MUAVENET ADD

<< Back to First Page | Continue with Next Page >>

Figure 18. Input Page 2



Input Page 3

Sector Design

#	Start Bearing	End Bearing	Inner Bound	Outer Bound
1	320	040	4000	9500
2	040	150	4000	9500
3	150	210	4000	8000
4	210	320	4000	9000

Check Sectors

Outer Sector

#	Start Bearing	End Bearing	Inner Bound	Outer Bound
1				
2				
3				

Check Outer Sectors | Draw the Screen

<< Back to Second Page | Continue with Next Page >>

Figure 19. Input Page 3

When the program user clicks on "draw the screen" the program displays the ASW Screen configuration in a pop-up window (see Figure5).

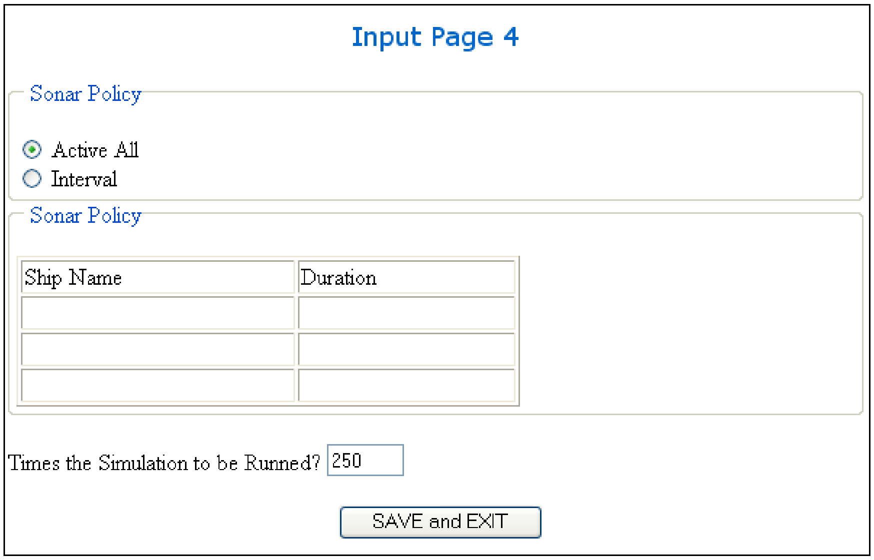


Figure 20. Input Page 4

The following output window appears showing the results from the simulation:

Convoy's Speed	Sonar Policy	# of Submarines	# of Successful Attacks	# of Unsuccessful Attacks	# of Ships
Med.Range Sonar Range	Lon. Range Sonar Rnage	# of Ships on the Inner Screen	# of Ships on the Outer Screen	Screen Design Information	Simulation Total Time
Submarine Battery Charge Capacity at Attack Time	Submarine Battery Charge Capacity after Attack Time	Submarine Battery Charge Capacity at End	Submarine Survival		

Figure 21. Output Table 1

A.	Convoy's Speed	10	B.	Convoy's Speed	12
	Total # of Ships on the Screen	4		Total # of Ships on the Screen	6
	Med. Ran. Sonar Range	4200		Med. Ran. Sonar Range	4890
	Lon. Ran. Sonar Range	5650		Lon. Ran. Sonar Range	7070
	Successful Attacks	85		Successful Attacks	65

Figure 22. Output Table 2

The simulation outcomes can also be shown as histograms. Examples of the histograms are shown in Figure 23 and Figure 24.

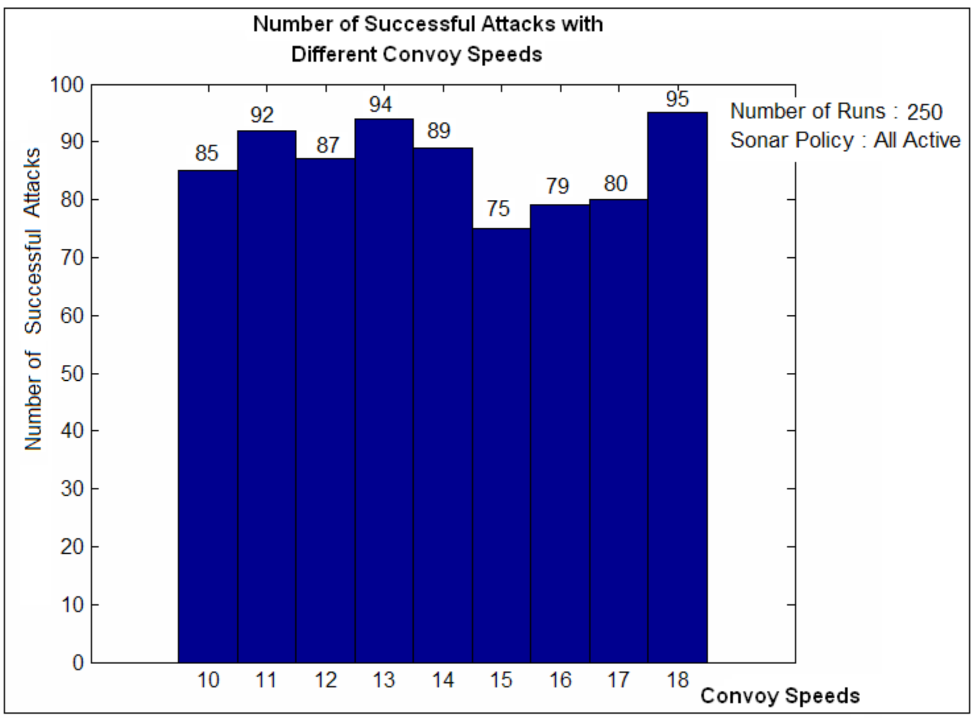


Figure 23. Number of Successful Attacks with Different Convoy Speeds

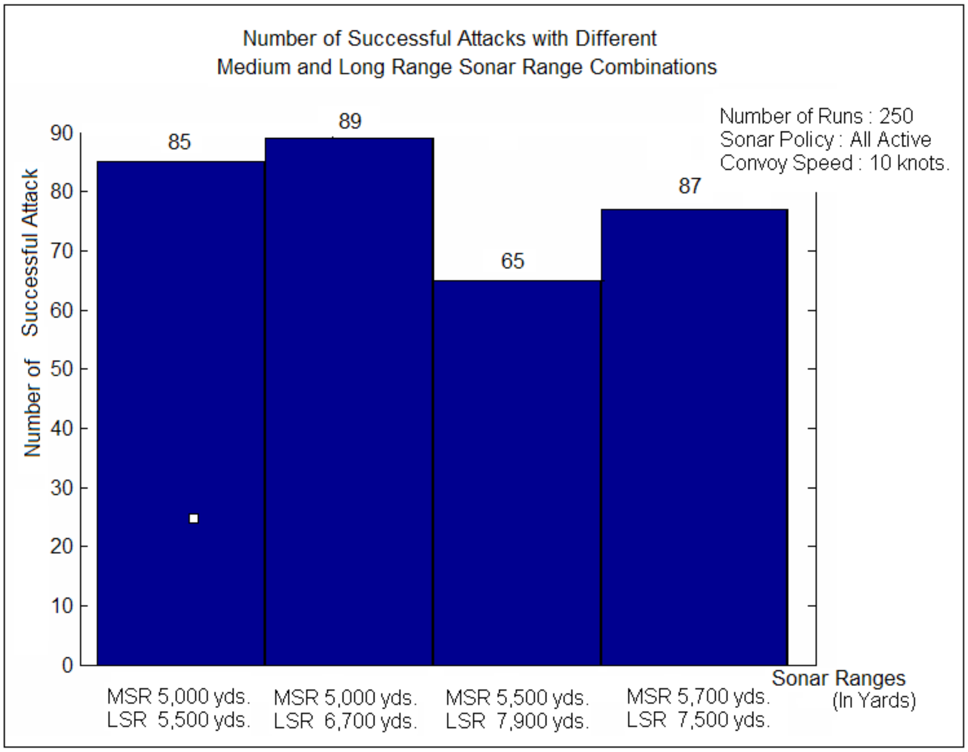


Figure 24. Number of Successful Attacks with Different Medium and Long Sonar Range Combinations

IV. IMPLEMENTED MODEL

This chapter explains the simulation model and program user interface. The user will gain a greater understanding of how to strategize and implement an ASW configuration screen by interfacing with the program. The chapter will also describe agent and object interactions and communications and how the user can monitor those interactions.

A. STRATEGY FOR CONFIGURATION OF THE ASW SCREEN

The overall program's effectiveness is measured by how often the HVU safely reaches its destination. The program user will attempt to find the optimal screen configuration for protecting the HVU from submarine attacks. In configuring an optimal ASW screen, the program user needs to consider 1) the measure of effectiveness (MOE) value and 2) the cost effectiveness of the number of ships used in the configuration.

The Measure of Effectiveness (MOE) function is:

$$MOE = \frac{\#\ of\ times\ HVU\ protected\ safely}{\#\ of\ total\ runs}$$

In the simulation, the user will be able to see the output for each ASW configuration and change the parameters of the program to improve the configuration. The most important factors to consider in configuring an ASW screen are the number of surface ships, the formation of the ships in the screen, the speed of the surface ships, and the ships' sonar ranges. However, in many military operations, the commanders are limited by the number of ships, the HVU maximum speed capacity, and effects of water conditions in sonar ranges. The HVU maximum speed capacity and water conditions are factors that the commanders cannot manipulate. Therefore, the most important variables in deciding an ASW screen are the number of ships and their formation on the screen. The number of ships chosen for the configuration will be determined by

whether adding additional ships to the configuration will greatly increase the MOE. The desired MOE will be determined by the commander for the particular operation.

B. AGENTS AND OBJECT INTERACTIONS

1. Agent Behaviors

The surface escort ships will be configured on the ASW screen around the HVU. The ships need to use their sonar in active mode to detect the submarine. The submarine's position will be unknown to the surface group at the beginning of the simulation. The surface ships will bear north in the ASW area.

The HVU's course will be 000° unless a zigzag pattern is implemented (see Figure 8: An Example of Zigzag Pattern for the Main Force, on page 25). The escort ships will be free to alter their speed and course while they attempt maximum coverage within their respective sectors. The ships will choose a preference search pattern within their sectors and discard any preference that falls below the threshold value for covering its sector (see page 37 for the effectiveness function for coverage of a sector). If the submarine fires a torpedo, the submarine's position at the time of attack will be revealed to the surface ships. The nearest two ships will move to the submarine's last known position (DATUM) at a speed of 21 knots (maximum speed is 25 knots). They will try to obtain a detection and form a barrier between the submarine and the HVU. The DATUM will be in progress for 15 minutes. At the end of the 15 minute period, the surface ships will return to their sectors and move north in the formation.

The submarine is the most important agent in the simulation. For a conventional submarine, battery level and speed are the most important issues. In the model, the submarine will make decision based on remaining battery percent; for example, when a submarine decides that it will not have sufficient remaining battery unit after the attack, it will cancel the attack and try to distance itself from the surface vessels.

The submarine will try to attack the HVU with the greatest probability of success, by advancing towards its target. However, the probability of a successful attack will be compromised by the submarine's consideration of its survivability. The submarine can detect surface ships with active sonar at a distance of 50,000 yards. The submarine will calculate a rendezvous point at which its initial position will be perpendicular (90° or 270°) to surface ships. This point is the shortest distance between the submarine and the surface ships. Hence, the submarine will minimize the distance traveled and its battery consumption. When the submarine arrives at the rendezvous point, it will be 10,000 yards away and have a bearing of 45° (east or west) relative to the HVU. If the submarine detects other surface ships within 7,500 yards—the maximum distance for the ship to detect the submarine—before it arrives at the rendezvous point, it has two options for attacking the HVU. The first option is for the submarine to attack if the following two conditions are met: 1) its distance from the HVU is less than or equal to the maximum torpedo range (17,000 yards) and 2) it has remained on the same course for the last two minutes (the time required for torpedo firing solution). The second attack option occurs when the submarine has remained on the same course for one minute at a distance of 17,000 yards from the HVU or less. In this case, it will draw a uniform random number between 0.0 and 1.0. If the number is less than, or equal to 0.7, then it will attack. If the submarine cannot meet these conditions for a safe attack, it will abort. The submarine's status will change to "escape" either after an attack or when it aborts. The submarine will alter its course to 180° to move away from the surface ships at a maximum speed of 24 knots for at least 15 minutes to avoid possible counterattacks. After 15 minutes, the submarine will calculate a new position for another attack when conditions are safe. The submarine will continue to attack unless 1) it has a battery level of less than or equal to 40% (required minimum battery level for an escape operation), or 2) the HVU has exited the ASW area to the north.

2. Object Behavior and Communications

In real life, many objects are not physical, but are needed to simulate the relationships. A torpedo's success cannot be known unless it has sunk a ship. However, It is not possible to fire a war head torpedo as part of practice. A torpedo might be defective, and can behave other than expected. There is no referee in reality but the object must be created to determine the relationships between the ships and the submarine.

a. Simulation Time Object:

The simulation time object calculates elapsed time synchronously with system time.

For example, if the user inputs into the ASW wizard 13:00 as the initial simulation time, the simulation time will be initialized as 13:00:00:000 (first field is for hour, second field is for minute, third field is for second, the last field is for millisecond). The simulation time object will continuously obtain system time (11:53:25:120) and will be updated using threads. Threads allow a program to efficiently perform multiple tasks simultaneously and enhance performance and functionality.[14]. The simulation time update thread will run inside the simulation time object to calculate elapsed time and update it. System time will be stored as "oldTime". Then the simulation time update thread will wait (sleep) for 60 milliseconds. After the 60 millisecond lapse, the simulation update thread will obtain system time and store it as "newTime". The simulation time object will be updated using the following equations:

$$\textit{elapsed system time} = \textit{newTime} - \textit{oldTime}$$

$$\textit{elapsed system time} = 11{:}53{:}25{:}180 - 11{:}53{:}25{:}120 = 60 \textit{ milliseconds}$$

14 Drake, J. D., cited 2004, Introduction to java threads [Available online at http://www.javaworld.com/javaworld/jw-04-1996/jw-04-threads.html.]

$$\text{elapsed simulation time} = \frac{\text{simulation time}}{\text{turn}} \times \text{elapsed system time}$$

$$\text{elapsed simulation time} = 15 \times \frac{120}{(\text{milliseconds})}$$

$$\text{elapsed simulation time} = 1800 \text{ milliseconds } (1 \text{ second} + 800 \text{ milliseconds})$$

The simulation time will be: 13: 00: 01: 800

Briefly, when one second elapses in system time, the simulation time will be forwarded 15 seconds.

b. Screen Object

The screen object obtains information regarding the sector bearings and ranges from the ASW Screen XML file. It configures the ship objects and positions them in the center of their sectors relative to the HVU, which is located at the center of the ASW screen. For example, if the sector has a beginning bearing of 0° and an ending bearing of 60° with an inner boundary at 4,000 yards and outer boundary at 9,000 yards, then the ship will have a bearing of 30° at a distance of 6,500 yards relative to the HVU's position.

c. Environment Manager Object

The environment manager object tracks the sonar status by obtaining the sonar policy from the XML files. It will control whether the sonar will be active or passive for each ship according to sonar policy in progress.

d. Track List Object

The track list object registers the ships' information such as identification numbers; names; course; speed; location; and bearing and distance (relative to the guide's ship). When other objects need to retrieve a surface ship's information they can query the track list object.

e. Submarine List Object

Similarly, the submarine list object retains the submarine's information such as its identification number, name, course, speed, location, bearing, and distance.

f. Referee Object

The referee object determines the detection of the ships and submarines. It checks the ships' sonar status and the distances between the ships and the submarine. For example, if the ship's sonar status is active, and the distance is within the submarine's passive sonar range (50,000 yards), then the referee object will notify the submarine that it detects a ship. The submarine will then obtain the ship's location, course, and speed from the referee object. If the ship's sonar status is passive, the submarine will be able to detect the ship within 15,000 yards (due to the propulsion and machinery noise), and it will obtain the ship's location, course, and speed from the referee object. If the submarine attacks the HVU, the referee will determine the attack's success. The referee will check the distance between the submarine and the HVU at the time of the attack (see Table 3: Probabilities of Successful Attack Based on Distance from an HVU, page 27). If a submarine fires a torpedo at a distance of 12,500 yards from the HVU, the probability of the kill is 0.48. The referee then draws a random number between 0.0 and 1.0 according to uniform distribution. If the random number drawn is less than or equal to 0.48, the attack is considered successful.

C. GRAPHIC USER INTERFACE

1. Initializing the Simulation

At the beginning of the program, the user will input the parameters and the required Extensible Markup Language (XML) files. The program user will be prompted by an ASW Input Wizard to input the parameters in three steps. The

user can move back and forth between the three steps by clicking on the “back” or “next” buttons while setting the desired parameters. In the first step, the user will input the simulation date and time; local time; and the course, speed, and location (latitude and longitude) of the guide ship in the formation (see Figure 25).

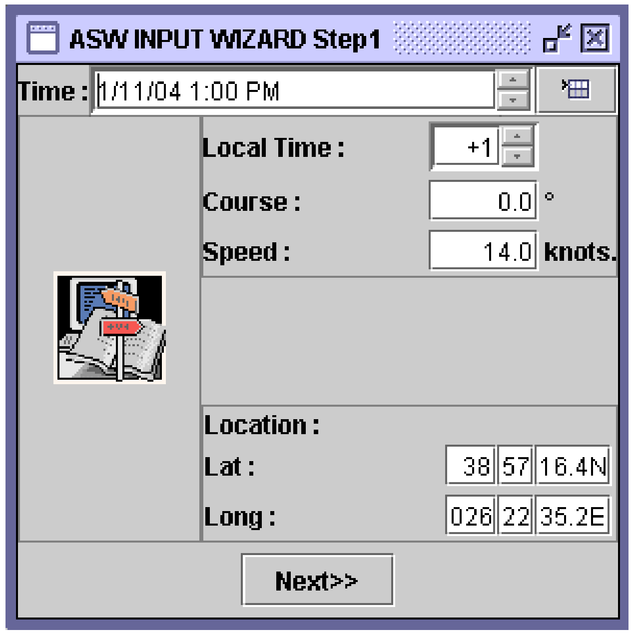


Figure 25. ASW Input Wizard Step1

The user can input the date-time by either clicking on the roller or the current date-time icon. The default date-time is 1/11/04, 1:00 pm. The local time range is -12 to +12. The course range is 000° to 359.9°. The speed ranges from 12 knots to 21 knots. The user will input the latitude and longitude for the location. For this simulation, the latitude ranges from 38° north to 40° north. The longitude ranges from 24° east to 30° east. The other ships in the formation will be positioned in reference to the guide ship’s location (see ASW screen design). If the user inputs a non-numerical value, the program will not continue to the next step.

In step two, the user will choose the area, screen, zigzag pattern, ship characteristics, and output file names (see Figure 26). (In addition, refer to Appendix A for an explanation of the XML files.)

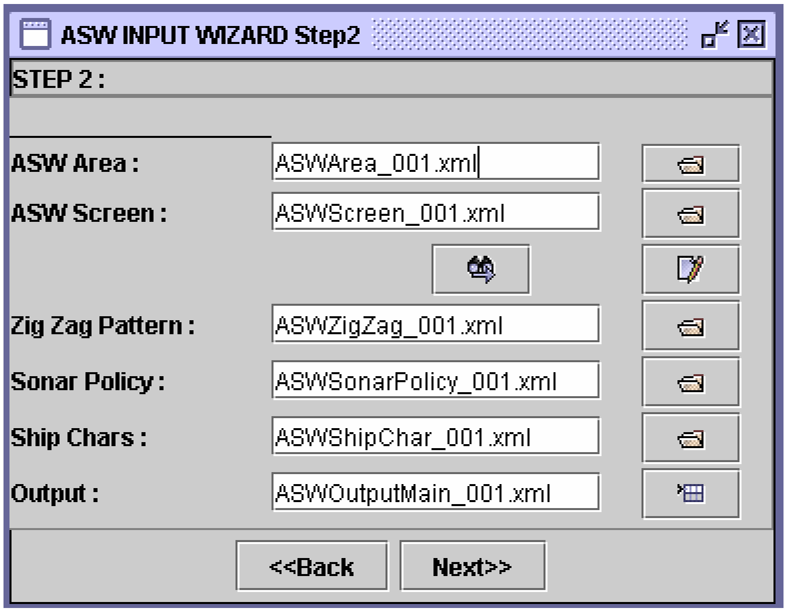


Figure 26. ASW User Input Wizard Step2

In this simulation, the area file consists of four-points which are the edges of the rectangular ASW area. Each point has an assigned letter from A to D with latitude and longitude coordinates. The user can choose from saved ASW screen files, or can create a new file with a different set of parameters (see Figure 27).

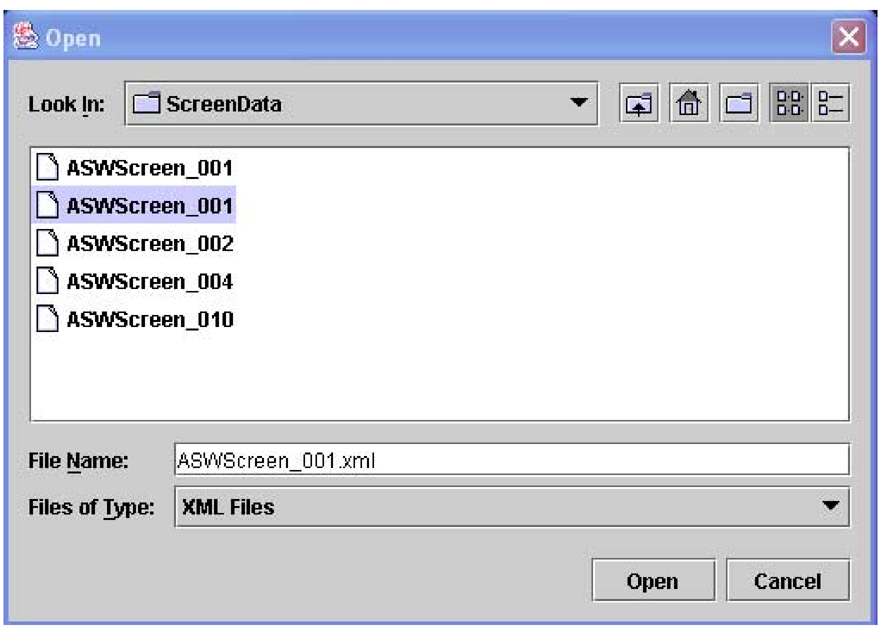


Figure 27. Choosing a Saved XML File for ASW Screen Configuration

The user can input the new set of parameters by clicking on the edit icon. A frame will appear and the user will be prompted to input the numerical values for the number of ships (four to eight), ships' names, screen value (one to number of ships), start bearing (0° to 359.9°), end bearing (0° to 359.9°), start range (in yards), end range (in yards), and inner screen (true or false). The starting bearing of one sector should be greater than, or equal to, the end bearing of another sector (see Figure 28). The inner screen sector values should add up to 360°. The outer screen sector begin ranges should be greater or equal to the inner sector end ranges. Inner screen values are "true" when the sectors belong to the inner screen; otherwise, they are "false." The same numerical values and constraints apply to the parameters for the helicopters. A helicopter can be positioned in a similar way within the sectors, as are the ships.

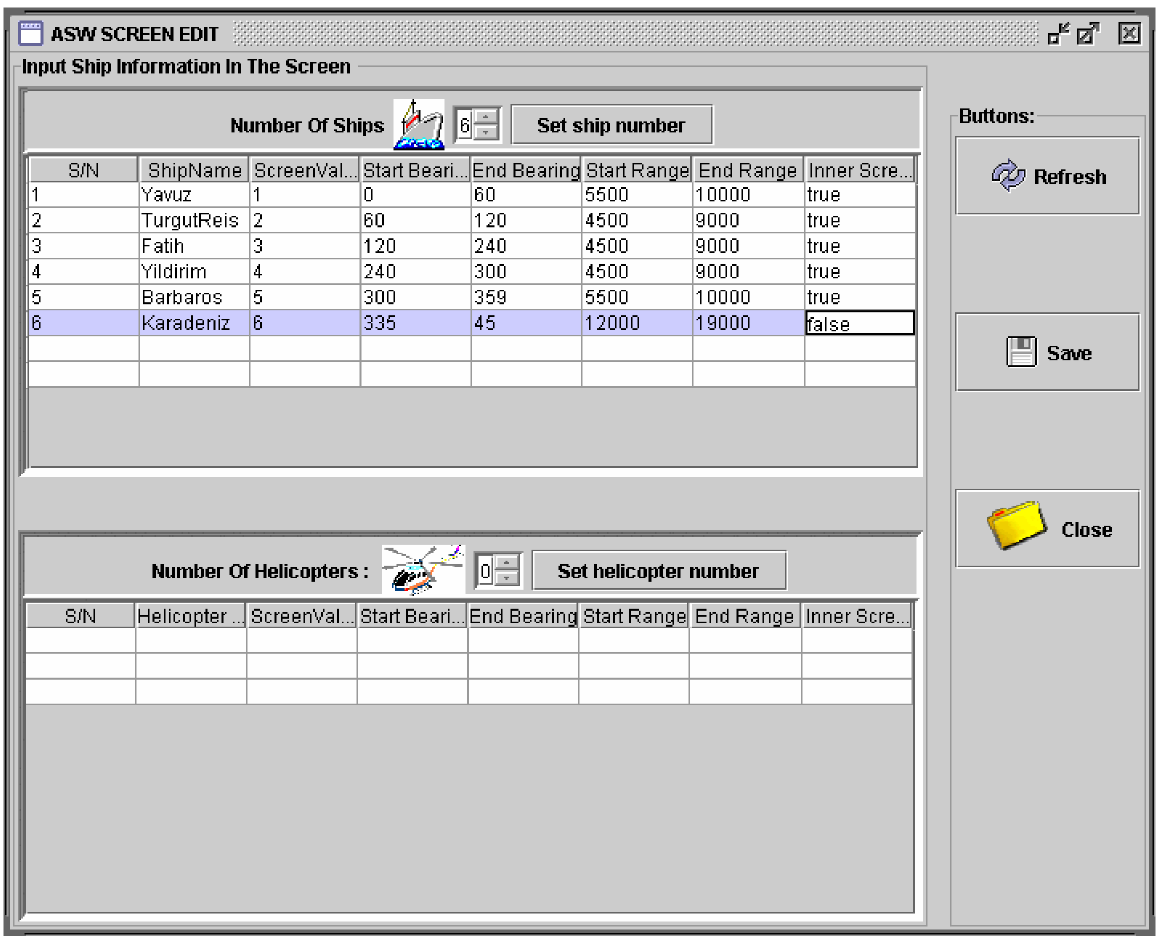


Figure 28. ASW Screen Edit Frame

After setting the parameters, the user must click on the "save" icon to save the set parameters. If the user clicks on the "close" button before saving the parameters, the frame will not close and the user will be warned to save the file. The user will choose the directory and file name to save the parameters to an XML file. The user can preview the ASW screen, incorporating the chosen parameters by clicking on the "preview" icon (see Figure 29).

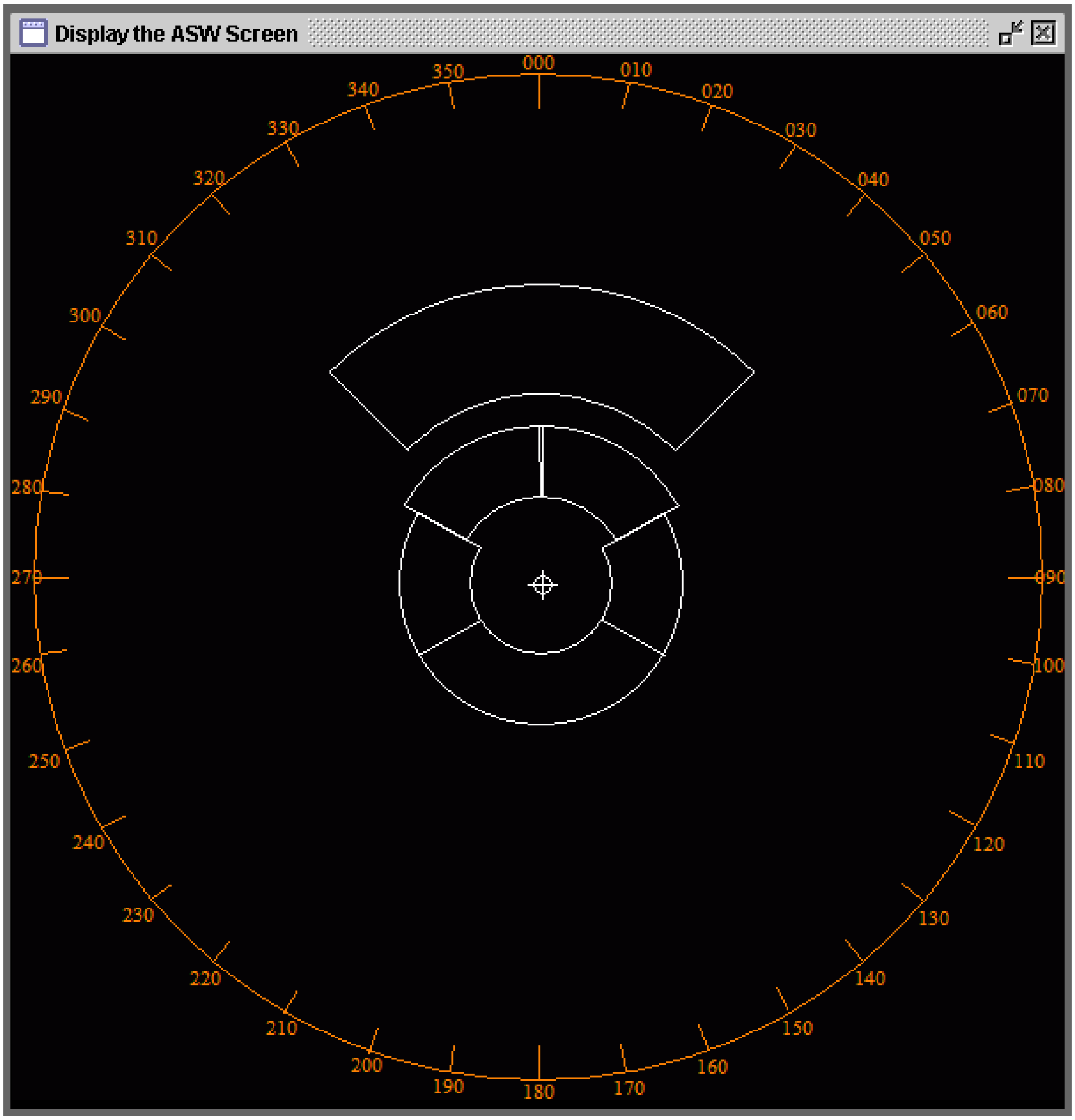


Figure 29. Preview of an ASW Screen

In step three, the user will choose a file name to save the track initialization file (see Figure 30). The default name is ASWTrack_001.xml. The user may also click on the “assign” icon for a different file name, i.e. ASWTrack_Mar6_1710.xml. Then the user will click on the “create” button and proceed to input values for sonar ranges: medium-range sonar values (3,000 to 7,000 yards) and long-range sonar values (4,500 to 6,800 yards). In the program there are two types of sonar: medium and long range sonar. The program user can input sonar ranges considering seasonal changes.

For medium range sonar:

Winter	min: 3,000 yards.	max 7,000 yards.
Summer	min: 2,000 yards.	max 3,000 yards.

The maximum range for an active sonar device is affected by two factors: 1) temperature at depth (gradient), 2) sonar device capability. Gradient differs for the same area in different seasons. In summer, a hull-mounted active sonar is expected to be efficient in a very short distance, where in winter, the range could be twice that of summer conditions. For the program, the user decides the maximum and minimum sonar ranges and inputs the values at the beginning of the program. The program user’s personal preferences influence the choice of sonar ranges. A minimum range is the worst case range, and the maximum range is the best case range that a sonar device’s detection ability. Before an ASW operation the commander will retrieve these ideal ranges from a bathythermograph device.

A sonar range file name will be chosen similarly to the track initialization file. The user will click on the “create” button to save the sonar range values.

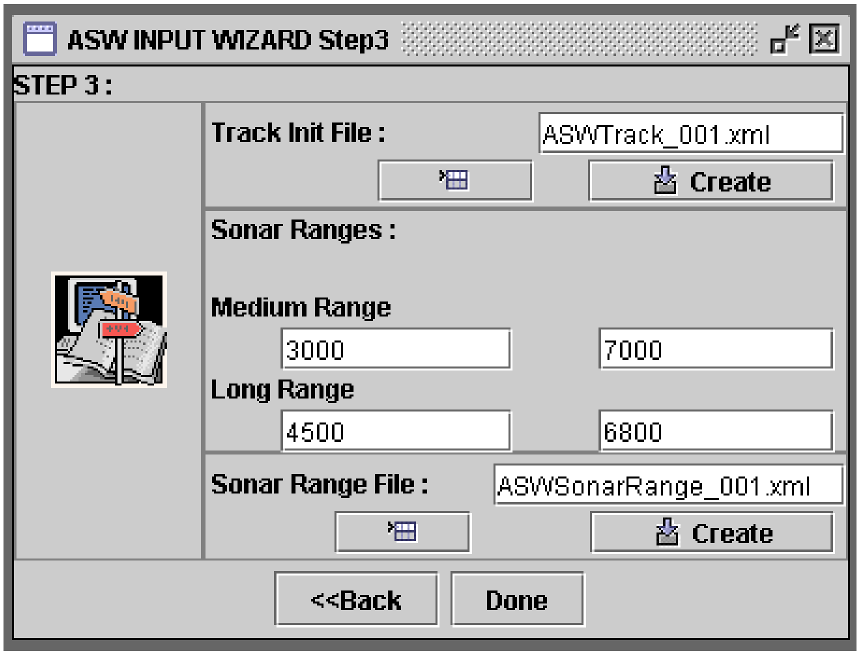


Figure 30. ASW Input Wizard Step3

To end the Wizard, the user will click on the "done" icon. If the user closes the wizard at any time during the three-step initializing of the simulation, the user will be warned that closing the wizard will end the program (see Figure 31).

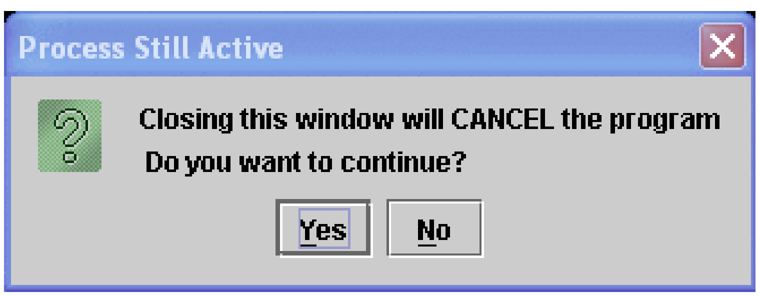


Figure 31. Warning Frame, Attempting to Close ASW Input Wizard

2. Horizontal Display Center

The horizontal display center (HDC) is a computer-generated version of a MEKO200 class frigate Combat Information Center (CIC) HDC (see Figure 32).

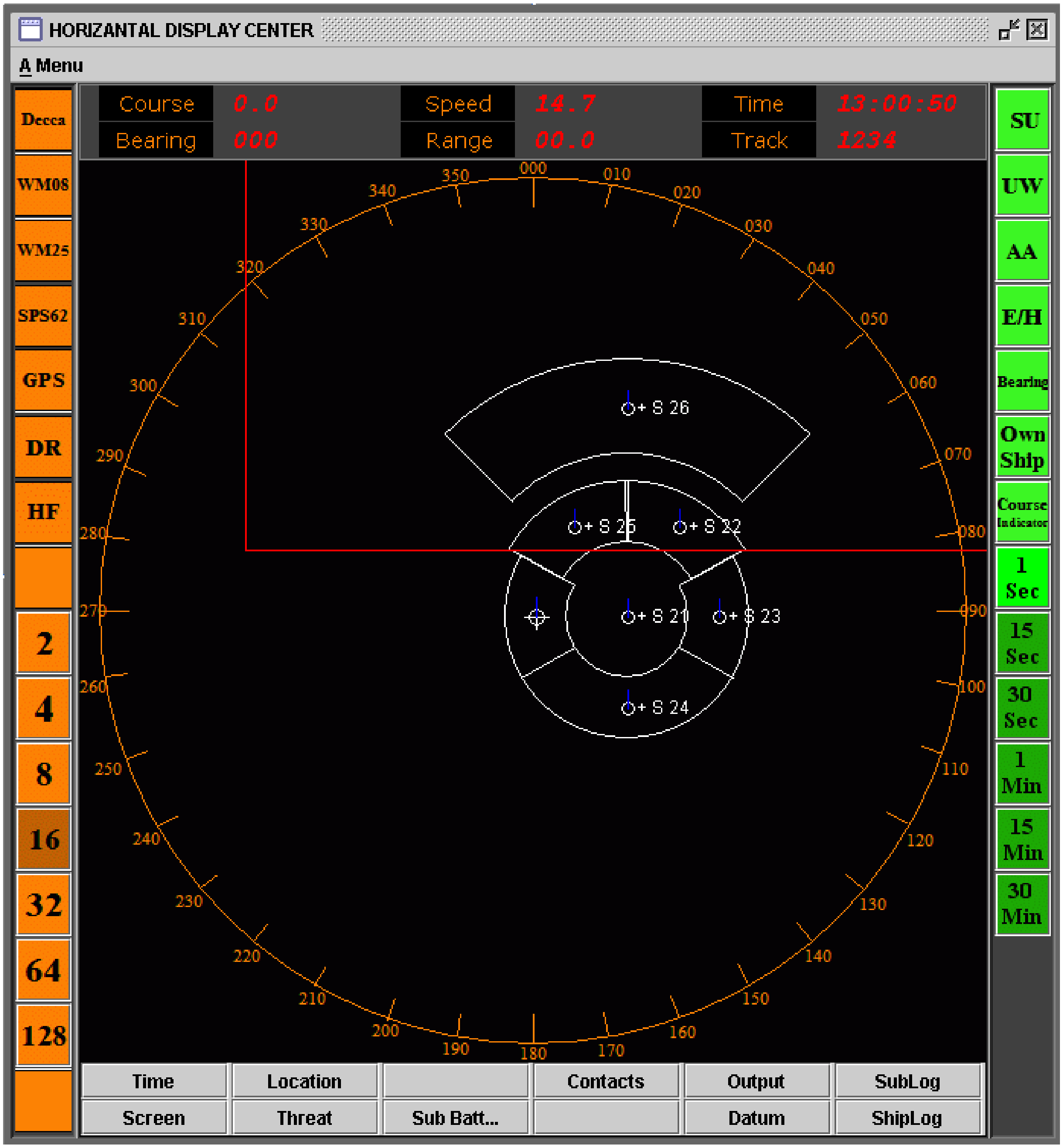


Figure 32. Horizontal Display Center

The HDC consists of five different panels: up, left, right, center, and down panels.

The up panel displays information on course, speed, and time for the guide ship.

The right panel has buttons used to choose radar types and magnification. The magnification button magnifies the center panel by a power of two (2, 4, 8, 16, 32, 64, 128) distance in nautical miles.

The left panel has buttons the user can choose to display the types of tracks and own ship indicators, courses, and bearings (surface, underwater, air, and electronic warfare tracks). Simulation time turn buttons are 1 sec, 15 sec, 30 sec, 1 min, 15 min, 30 min.

The center panel displays the ASW area and ASW screen in a compass. It also displays the ships (tracks) and submarine positions. The guide ship is positioned at the center of the panel and the other ships are positioned in reference to the guide ship.

The down panel displays buttons for determining the time, location, contact information, submarine and ship logs, submarine battery capacity level, threat, screen and datum. The time frame displays the date and time of the simulation (see Figure 33). The location frame displays the location of the guide ship, in latitude and longitude (see Figure 34).

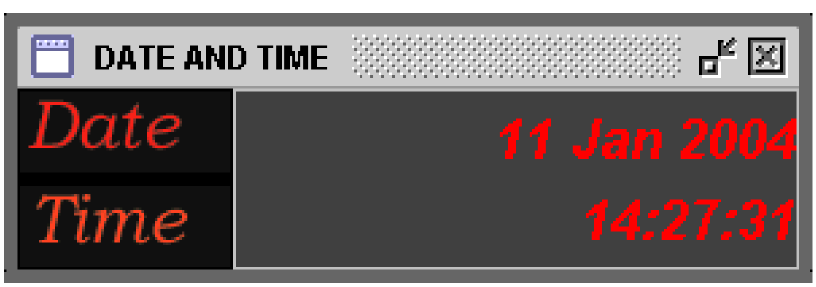


Figure 33. Date and Time Frame

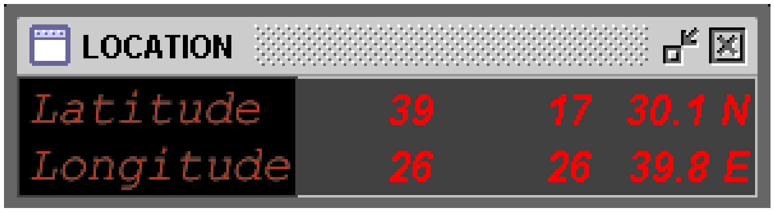


Figure 34. Location Frame

The contact information frame shows the identification number, type, bearing, distance, location, course, speed, and classification of the other ships in the formation (see Figure 35).

Figure 35. Contact Information Frame

The user can input the ship track identification number to set the default contact information or set the information manually.

The submarine and ship logs display the submarines' and ships' status and decisions (see Appendix C). The submarine battery capacity level display shows the remaining battery unit and battery percent. The user can also display the track assessment in the center panel by clicking on the threat button. When

the user clicks on the “screen” button, a screen with be displayed in the center panel according to the chosen magnification of display center.

D. MONITORING INTERACTION

1. Display Panel

The display panel shows the ASW configurations of ship and submarine objects enclosed within an orange compass. The diameter of the compass can be adjusted by the magnification button. Surface ships are represented by white circles, which is a symbol of friendly surface track (see Figure 36).

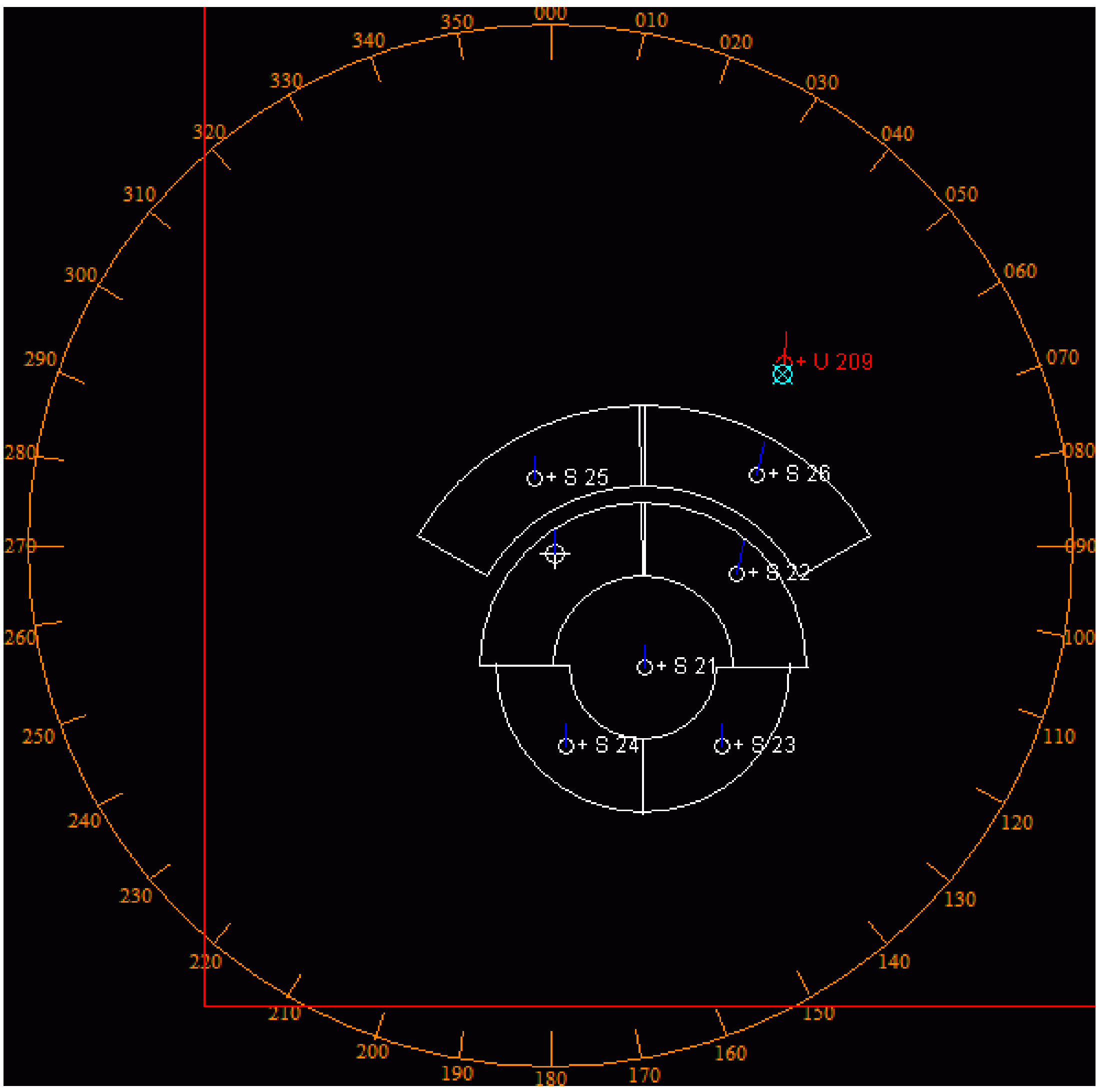


Figure 36. Display Panel

The submarine is represented by a red, inverted, half-diamond, which symbolizes an enemy, underwater track. The courses are represented by straight lines: blue for surface ship tracks and red for submarine. The ASW area is shown as a square with red sides. The DATUM is represented by a cyan "X" enclosed in a circle. The DATUM symbol will appear for fifteen minutes in simulation time only when the submarine fires a torpedo.

2. Submarine Battery Display

The submarine battery display has two panels (see Figure 37).

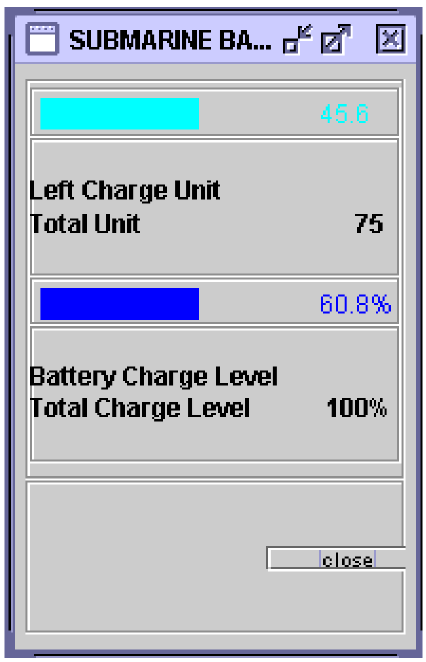


Figure 37. Submarine Battery Display

The first panel shows the remaining unit represented by a rectangular bar. The second panel displays the remaining percent, also represented by a rectangular bar. The remaining unit can be calculated using the battery consumption table (see Table 6).

Speed (In Knots)	Battery Consumption (Unit/Hour)
0-5	1
6-7	2
8-9	3
10-11	4
12-13	8
14	12
15	14
16	15
17	20
18	25
19	39
20	40
21	50
22	60
23	75
24	90
25	100

Table 6. Battery Consumption Based on Different Speed

For example, a submarine with 64.0 battery units at the current time, at a speed of 21 knots, after 15 simulation time elapsed, the remaining battery unit can determined by the following equations:

$$\text{Remaining unit} = \text{remaining unit} - \frac{\left(\begin{matrix}\text{elapsed time}\\ \text{(sec)}\end{matrix} \times \begin{matrix}\text{battery consumption}\\ \text{(unit/hour)}\end{matrix} \right)}{\left(60 \text{ (min)} \times 60 \text{ (sec)} \right)}$$

Remaining unit will be: 64.0 – ((15.0 x 50)/3,600.0) = 63.79

In a Type-209 submarine which has a total 75 battery units, the remaining percent will be calculated by the fallowing equations:

$$\text{Remaining Percent} = \left(\frac{\text{remaining unit}}{\text{total unit}} \right) \times 100.0$$

Remaining percent will be: (63.79/75.0) x 100.0 = 85.05%

3. Event Loggers

The event loggers display text messages for each event change in a tree. It will register the event information regarding when and how a change occurs for the submarine and ships (see Figure 38).

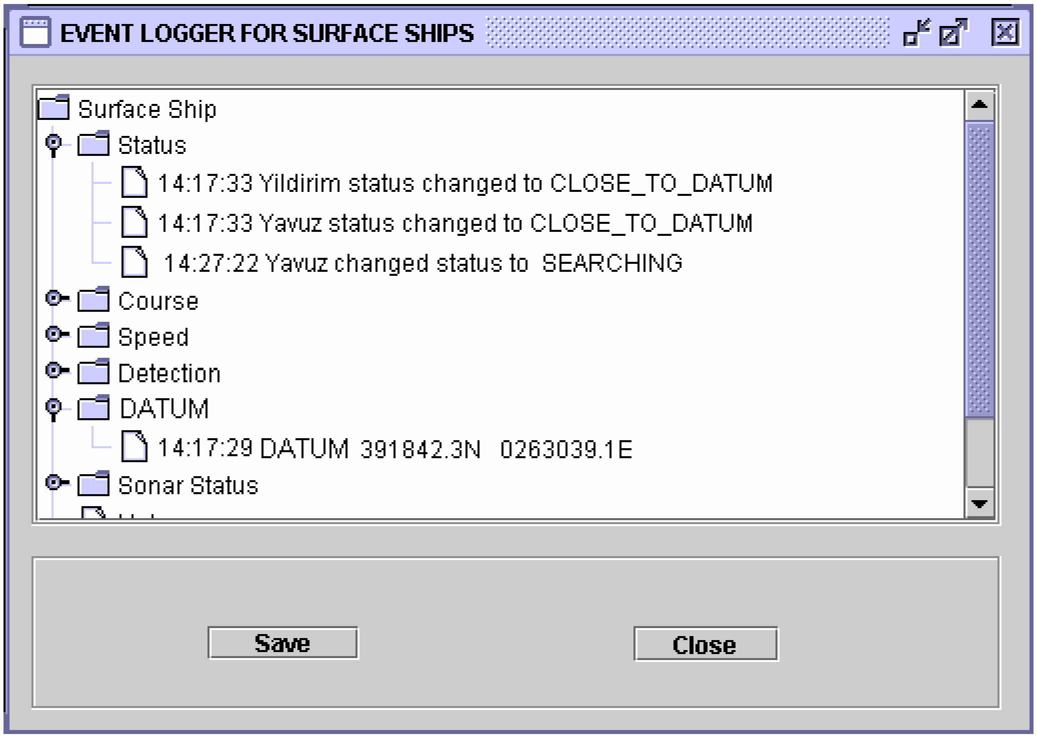


Figure 38. Event Logger for Surface Ships

When an event occurs, the event loggers will register a message at the end of the leaf for each event category. The user can learn about event categories such as the status, course, speed, detection, DATUM, and sonar status for the surface ships by checking the event logger. The user can also investigate the submarine's status, course, speed, detection, contact loss, move for attack, and move for survival (see Figure 39).

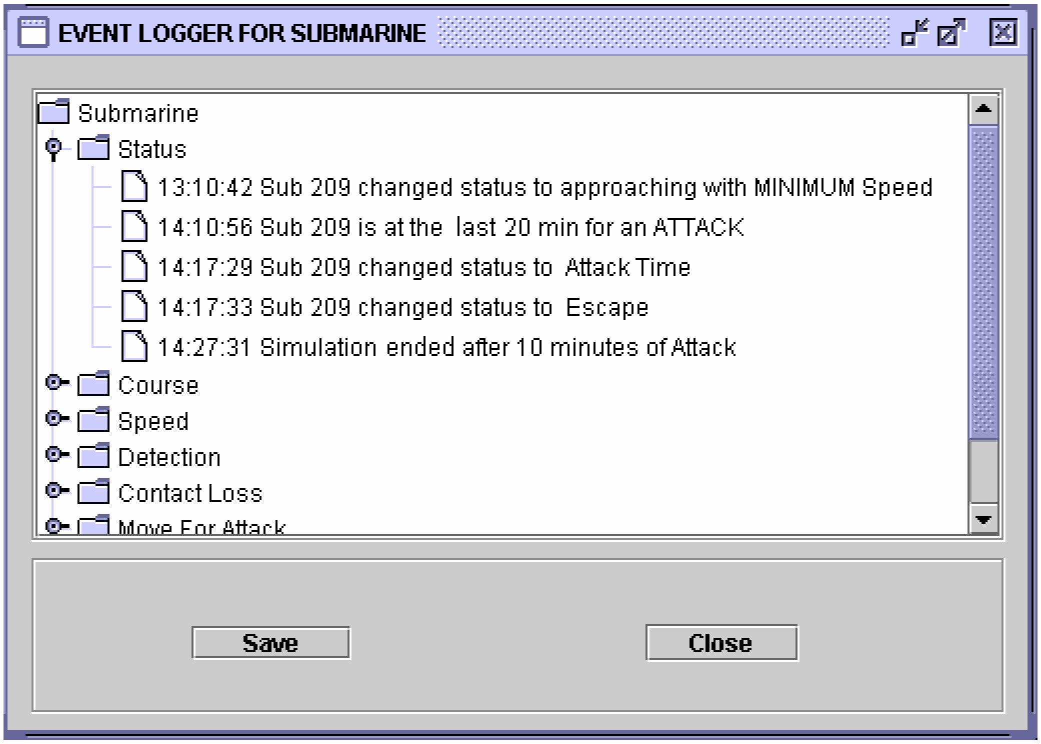


Figure 39. Event Logger for Submarine

4. Contact Display

The contact display is a frame that shows the surface ships' basic information such as identification number, type, bearing, distance, latitude, longitude, course, speed, and classification (see Figure 35).

V. ANALYSIS

It is not possible to analyze the space of all simulations that can be run on the simulator described in this work, since there are infinitely many such simulations. Thus, a thorough analysis of the program is a project of itself that may be addressed in the future. The purpose of this chapter is to present a simple analysis of sample configurations. The outcomes of the simulation are discussed and the findings allow the user to investigate other possible configurations.

A. EXPERIMENT WITH SAMPLE CONFIGURATIONS

1. Goal of Experiment

The experiment explored how the configuration and number of ships affect the Measure of Effectiveness (MOE). The simulation was run with four, five, and six ships and each configuration was run for ten times. The configuration with the number of ships that yielded the greatest MOE was chosen. The positions of the ships from the six ships configuration was then changed to see if a different configuration with the same number of ships would yield a greater MOE. The parameters (sonar range and convoy speed) for all configurations were identical for all configurations. Medium-range sonar is chosen for all configurations, since the majority of Turkish naval ships have medium-range sonar. To further simplify the configurations for ease of analysis, a zig-zag pattern was not implemented. The submarine began at the same position for all simulations. From this experiment, the program user will be able to determine how the number of ships in a configuration affects overall coverage of ASW screen and whether a change in the configuration greatly impacts the MOE value.

2. Description of Configurations

The inputted medium sonar range was 3,000 yards (minimum) and 4,000 yards (maximum) for all the runs. The main force speed was 14 knots. The ships were searching their sectors at a speed between eight to eighteen knots.

a. ASW Screen Configuration with Four Ships

In this configuration, four ships (TCG Yavuz, TCG Turgutreis, TCG Fatih, TCG Yildirim) were positioned on the inner sector (see Table 7 and Figure 40). Each ship is positioned at 90° and their frontal inner sector bounds begin at a distance greater than the rear sector bounds. The frontal sector bounds began at a distance of 5,500 yards and rear sector bounds began at a distance of 4,500 yards.

SECTOR DESIGN

Sector ID	Ship Name	Start Bearing	End Bearing	Inner Bound	Outer Bound	Inner Screen
1	TCG Yavuz	000	090	5500	10000	true
2	TCG Turgutreis	090	180	4500	9000	true
3	TCG Fatih	180	270	4500	9000	true
4	TCG Yildirim	270	360	5500	10000	true

Table 7. ASW Screen Configuration with Four Ships

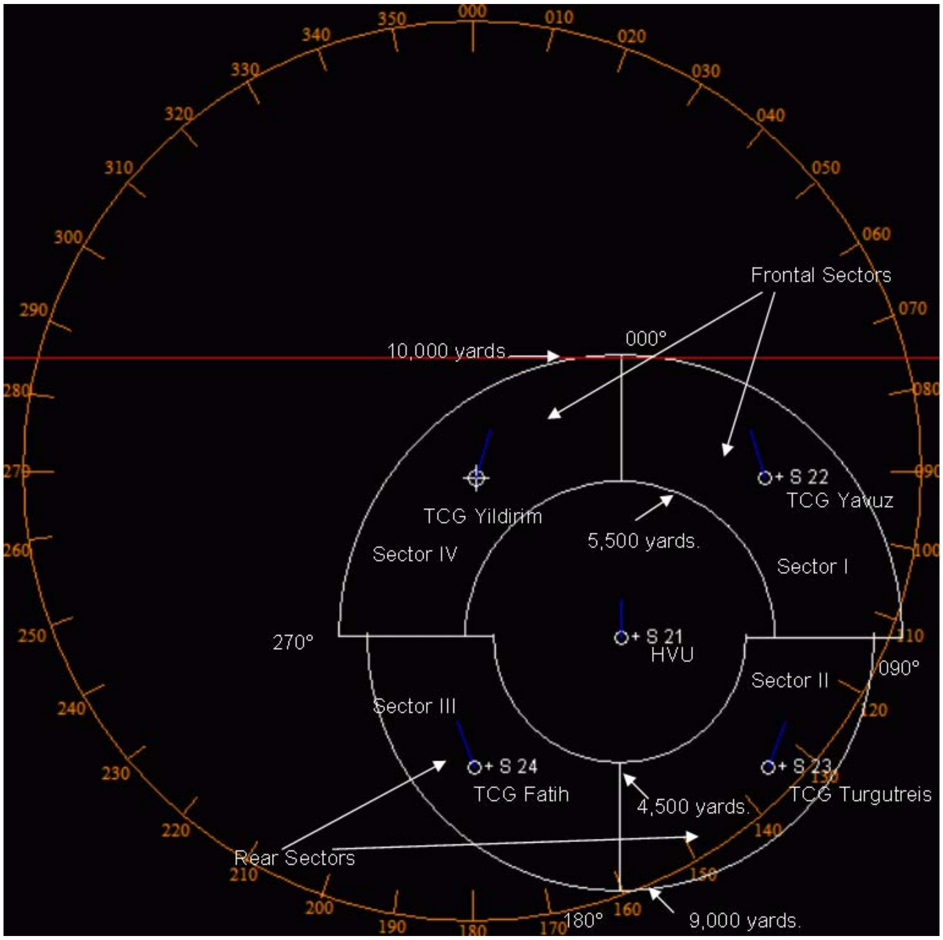


Figure 40. ASW Screen Design with Four Ships

The sonar policy allowed only two ships to have their sonar on active mode for a specific time (see Table 8). From the top of the hour between 00-10, all ships are in passive mode. At 10-20 TCG Yildirim and TCG Turgutreis sonar were active. At 20-30 TCG Yavuz and TCG Fatih sonar were active. At 30-40 TCG Yildirim and TCG Fatih sonar were active. Then at 40-00 TCG Yavuz and TCG Fatih sonar were active. This sonar policy allowed only one ship to be active in the frontal sectors, while one ship was active in the rear sectors. The sonar policy for the four ships is shown in Table 8.

	Time Slices in Each Hour (In Minutes)					
	00-10	10-20	20-30	30-40	40-50	50-00
Name of the Ship Using Sonar In Active Mode	-	TCG Yildirim TCG Turgutreis	TCG Yavuz TCG Fatih	TCG Yildirim TCG Turgutreis	TCG Yavuz TCG Fatih	TCG Yavuz TCG Fatih

Table 8. Sonar Policy for Four-Ship Screen Configuration

b. ASW Screen Configuration with Five Ships

In this configuration, five ships (TCG Yavuz, TCG Turgutreis, TCG Fatih, TCG Yildirim and TCG Barbaros) were positioned on the inner sectors (see Table 9 and Figure 41). The frontal ships were assigned to 60° with sector bounds beginning at 5,500 yards. Sectors two and four were positioned at 72°, 4,500 yards from the HVU. The ship at the rear sector was positioned at 96° with the sector bounds beginning at 4,500 yards from the HVU.

SECTOR DESIGN

Sector ID	Ship Name	Start Bearing	End Bearing	Inner Bound	Outer Bound	Inner Screen
1	TCG Yavuz	000	060	5500	10000	true
2	TCG Turgutreis	060	132	4500	9000	true
3	TCG Fatih	132	228	4500	9000	true
4	TCG Yildirim	228	300	4500	9000	true
5	TCG Barbaros	300	360	5500	10000	true

Table 9. ASW Screen Configuration with Five Ships

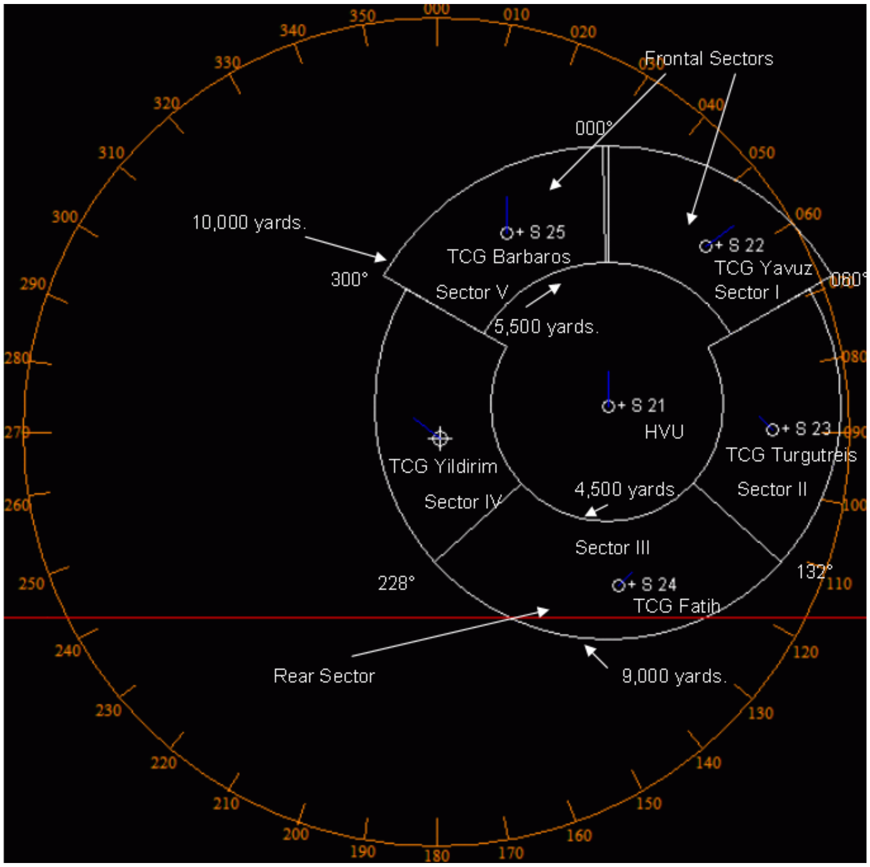


Figure 41. ASW Screen Configuration for Five Ships

The sonar policy allowed one, two or three ships to be in active mode for ten-minute intervals (see Table 10). From the top of the hour between 00-10 only TCG Barbaros was in active mode. From 10-20, TCG Yildirim and TCG Turgutreis were active. From 20-30, TCG Yavuz and TCG Fatih were active. From 30-40, TCG Yildirim TCG Turgutreis and TCG Barbaros were active. From 40-00 TCG Yavuz and TCG Fatih were active. The sonar policy for the five ships is shown in Table 10.

	Time Slices in Each Hour (In Minutes)					
	00-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-00**
Name of the Ship Using Sonar In Active Mode	TCG Barbaros	TCG Yildirim TCG Turgutreis	TCG Yavuz TCG Fatih	TCG Yildirim TCG Turgutreis TCG Barbaros	TCG Yavuz TCG Fatih	TCG Yavuz TCG Fatih

Table 10. Sonar Policy for Five-Ship Screen Configuration

c. *ASW Screen Configuration with Six Ships (First Configuration)*

In this configuration, five ships (TCG Yavuz, TCG Turgutreis, TCG Fatih, TCG Yildirim, and TCG Barbaros) were positioned on the inner sector and one ship (TCG Orucreis) was assigned to the outer sector (see Table 11 and Figure 42). The inner sector design was the same as the previous five-ship ASW Screen Configuration. The outer sector began at an angle of 315° and ended at 45° with sector bounds at 12,000 and 16,000 yards from the HVU.

SECTOR DESIGN

Sector ID	Ship Name	Start Bearing	End Bearing	Inner Bound	Outer Bound	Inner Screen
1	TCG Yavuz	000	060	5500	10000	true
2	TCG Turgutreis	060	132	4500	9000	true
3	TCG Fatih	132	228	4500	9000	true
4	TCG Yildirim	228	300	4500	9000	true
5	TCG Barbaros	300	360	5500	10000	true
6	TCG Orucreis	045	315	12000	16000	false

Table 11. ASW Screen Configuration with Six Ships

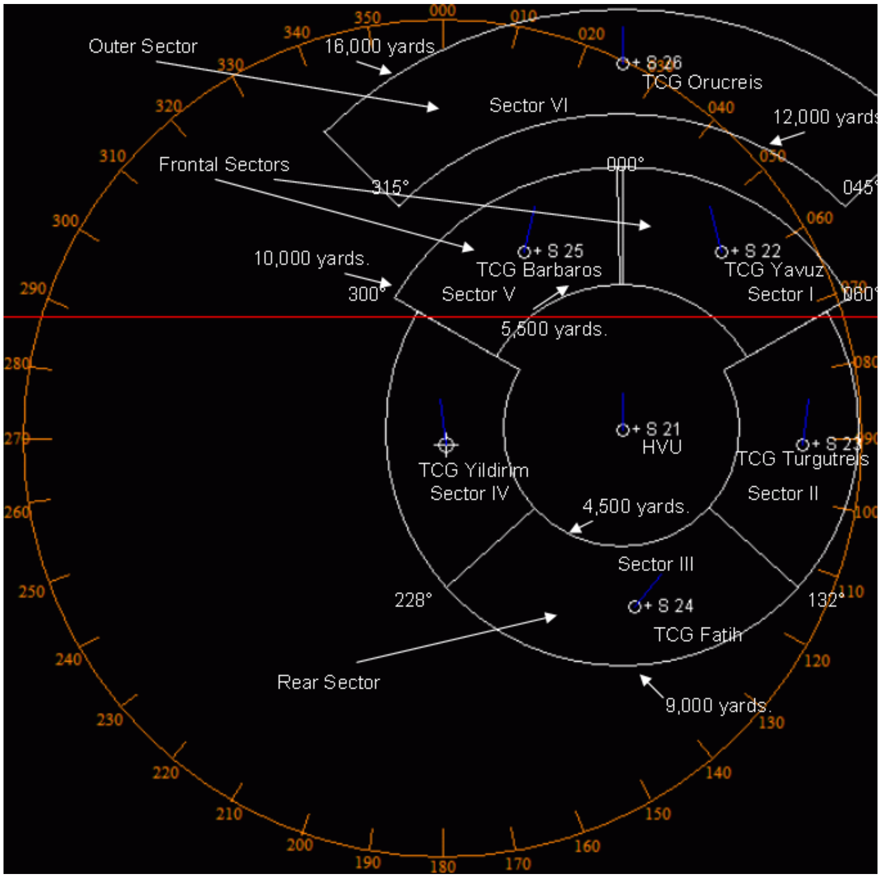


Figure 42. ASW Screen Configuration for Six Ships

The sonar policy allowed one, two or three ships to be in active mode for ten minutes intervals (see Table 12). From the top of the hour between 00-10, TCG Barbaros and TCG Fatih were in active mode. From 10-20 TCG Barbaros and TCG Turgutreis were active. From 20-30 TCG Orucreis, TCG Yildirim, and TCG Turgutreis were active. From 30-40, TCG Yavuz and TCG Yildirm were active. From 40-50, TCG Barbaros and TCG Yavuz were active. From 50-00 TCG Orucreis and TCG Fatih were active. Table 12 shows the sonar policy for six ships.

	Time Slices in Each Hour (In Minutes)					
	00-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-00**
Name of the Ship Using Sonar In Active Mode	TCG Orucreis TCG Fatih	TCG Barbaros TCG Turgutreis	TCG Orucreis TCG Yildirim TCG Turgutreis	TCG Yavuz TCG Yildirim	TCG Barbaros TCG Yavuz	TCG Orucreis TCG Fatih

Table 12. Sonar Policy for Six-Ship Screen Configuration

d. Second ASW Screen Configuration with Six Ships (Second Configuration)

The ASW Screen configuration was changed to potentially improve the MOE from the previous configuration (see Table-13 and Figure 43). The main difference was that two ships are positioned on the outer sector instead of one ship (TCG Barbaros and TCG Orucreis). The outer sectors began at 315° and ends at 45°. The sector boundaries were 11,000-15,000 yards from the HVU. The frontal sectors began at 75°, and the rear sectors began at 105°. The frontal sectors were positioned at 5,500 yards, and the rear sectors positioned at 4,500 yards from the HVU.

SECTOR DESIGN

Sector ID	Ship Name	Start Bearing	End Bearing	Inner Bound	Outer Bound	Inner Screen
1	TCG Yavuz	000	075	5500	10000	true
2	TCG Turgutreis	075	180	4500	9000	true
3	TCG Fatih	180	285	4500	9000	true
4	TCG Yildirim	285	360	5500	9000	true
5	TCG Barbaros	315	360	11000	15000	false
6	TCG Orucreis	000	045	11000	15000	false

Table 13. ASW Screen Configuration with Six Ships

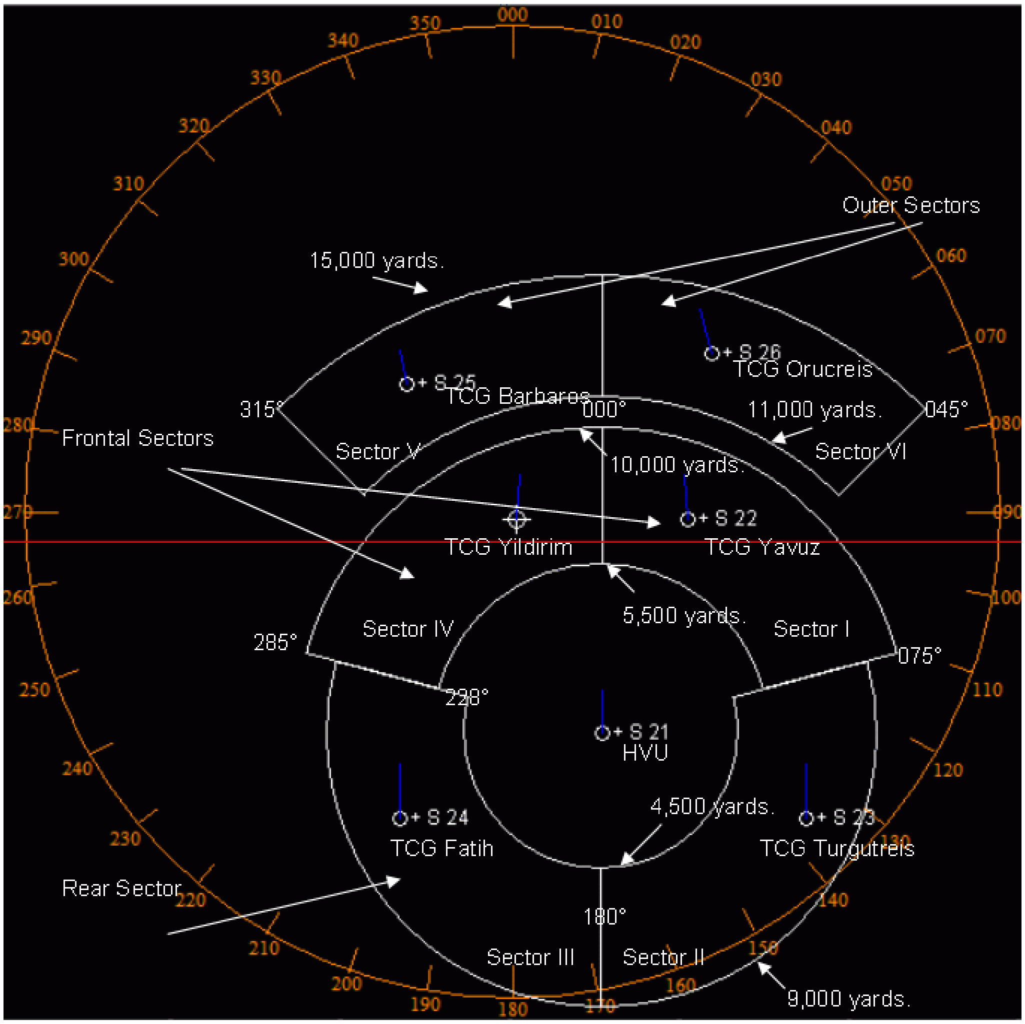


Figure 43. ASW Screen Configuration for Six Ships

The sonar policy allowed one, two or three ships to be in active mode for 10 minutes intervals (see Table 14). From the top of the hour between 00-10, TCG Barbaros and TCG Yavuz were in active mode. From 10-20, TCG Orucreis and TCG Yildirim were active. From 20-30, TCG Orucreis, TCG Fatih and TCG Turgutreis were active. From 30-40, TCG Yavuz and TCG Yildirim were active. From 40-50, TCG Barbaros and TCG Yavuz were active. From 50-00, TCG Orucreis and TCG Yildirim were active. See Table 14 for the sonar policy for the six ships.

	Time Slices in Each Hour (In Minutes)					
	00-10	10-20	20-30	30-40	40-50	50-00
Name of the Ship Using Sonar In Active Mode	TCG Barbaros TCG Yavuz	TCG Orucreis TCG Yildirim	TCG Orucreis TCG Fatih TCG Turgutreis	TCG Yavuz TCG Yildirim	TCG Barbaros TCG Yavuz	TCG Orucreis TCG Yildirim

Table 14. Sonar Policy for Six-Ship Screen Configuration

B. RESULTS

1. Results for Four Ships

The submarine attacked the HVU 17 times. It was successful nine out of seventeen of those attempts. See Table 15 for a more detail description of the attacks.

	Attack Distances		Submarine's Success		Battery Unit at Attack Time (%)		Submarine's Status at End
Run Time Serial Number	First Try	Second Try	First Try	Second Try	First Try	Second Try	
1	13,717		Successful		74.2		Survived
2	13,659	8,672	Unsuccessful	Successful	74.11	45.33	Survived
3	13,561	8,248	Unsuccessful	Unsuccessful	74.13	46.46	Survived
4	13,626	8,319	Unsuccessful	Successful	74.06	47.52	Survived
5	13,625	8,362	Unsuccessful	Successful	73.98	46.28	Survived
6	13,698		Successful		74.1		Survived
7	13,705	8,682	Unsuccessful	Successful	73.97	46.52	Survived
8	13,527	8,727	Unsuccessful	Successful	74.19	45.8	Survived
9	13,550		Successful		74.1		Survived
10	12,760	8,569	Unsuccessful	Successful	71.59	44.81	Survived

Table 15. The Results for Four-Ship ASW Configuration

Submarine attacked at distances between 12,760-13,717 yards with an average distance of 13,543 yards (see Figure 44).

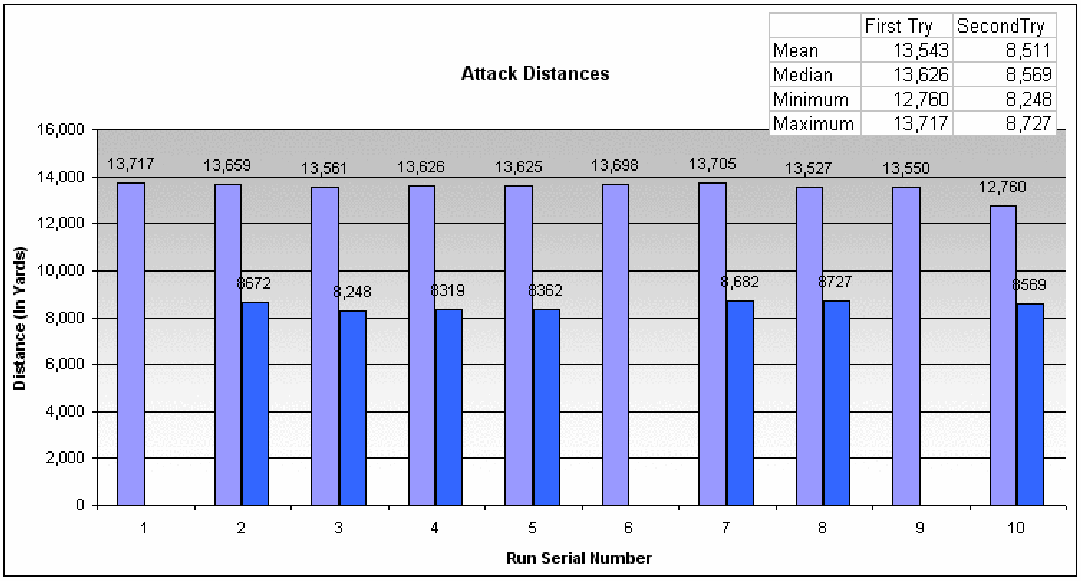


Figure 44. Attack Distances in Each Try

The surface ship's success rate was 47% for protecting the HVU. The MOE was 0.1 (see Figure 45).

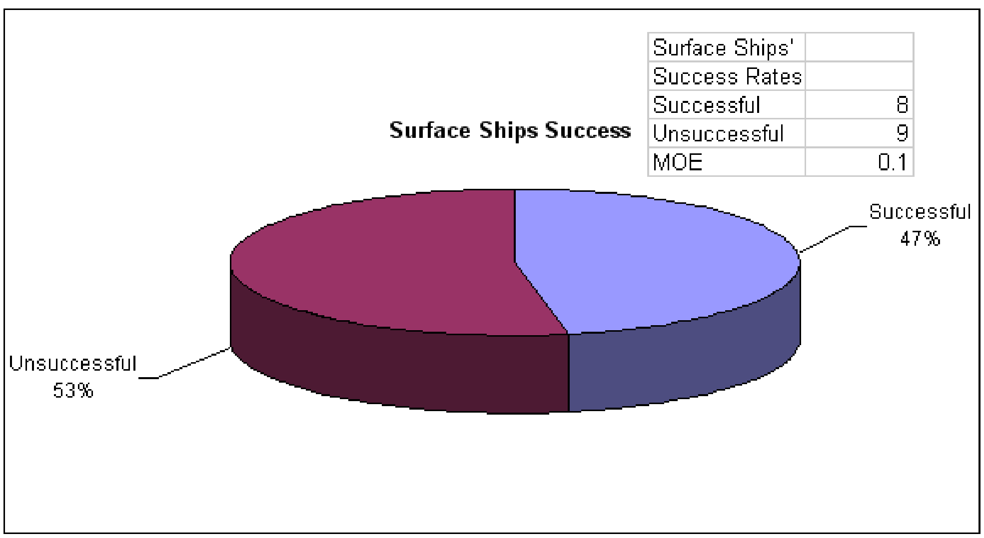


Figure 45. Surface Ships' Success for the Configuration

The surface ships could not sink the submarine (see Figure 46).

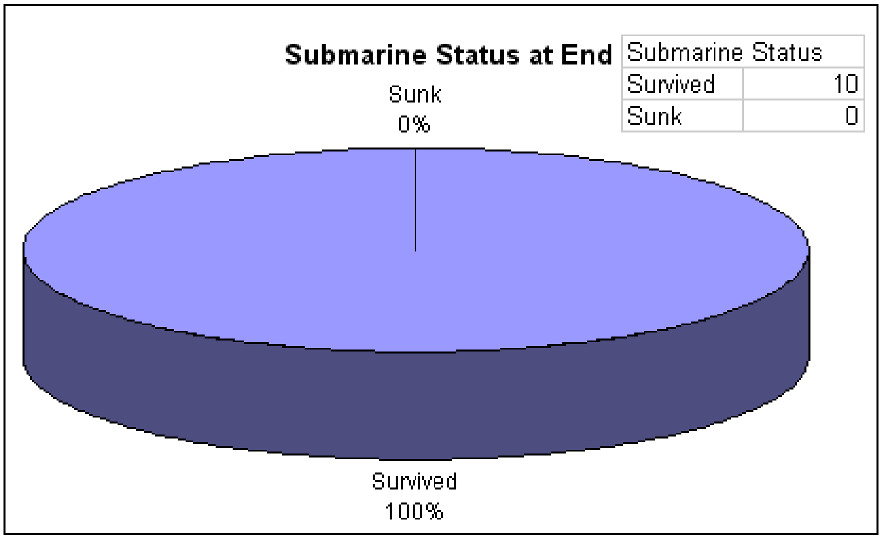


Figure 46. Submarine's Status at End

2. Results for Five Ships

The submarine attacked the HVU 13 times. The submarine was successful at attacking the HVU in three of the thirteen attempts. See Table 16 for the details of the results of those attacks.

	Attack Distances		Submarine's Success		Battery Unit at Attack Time (%)		Submarine's Status at End
Run Time Serial Number	First Try	Second Try	First Try	Second Try	First Try	Second Try	
1	11,265		Successful		71.2		Survived
2	14,237		Successful		70.2		Survived
3	14,359	16,729	Unsuccessful	Unsuccessful	69.7	61.6	Sunk
4	14,237		Unsuccessful		73.24		Sunk
5	14,228		Successful		73.18		Survived
6	14,016		Unsuccessful		73.13		Sunk
7	14,220	16,651	Unsuccessful	Unsuccessful	72.06	57.56	Sunk
8	14,182		Unsuccessful		73.2		Sunk
9	14,118	16,517	Unsuccessful	Unsuccessful	73.29	58.72	Sunk
10	14,527		Unsuccessful		73.17		Sunk

Table 16. The Results for Five-Ship ASW Configuration

Submarine attacked at distances between 11,265-14,527 yards with an average distance of 13,939 yards (see Figure 47).

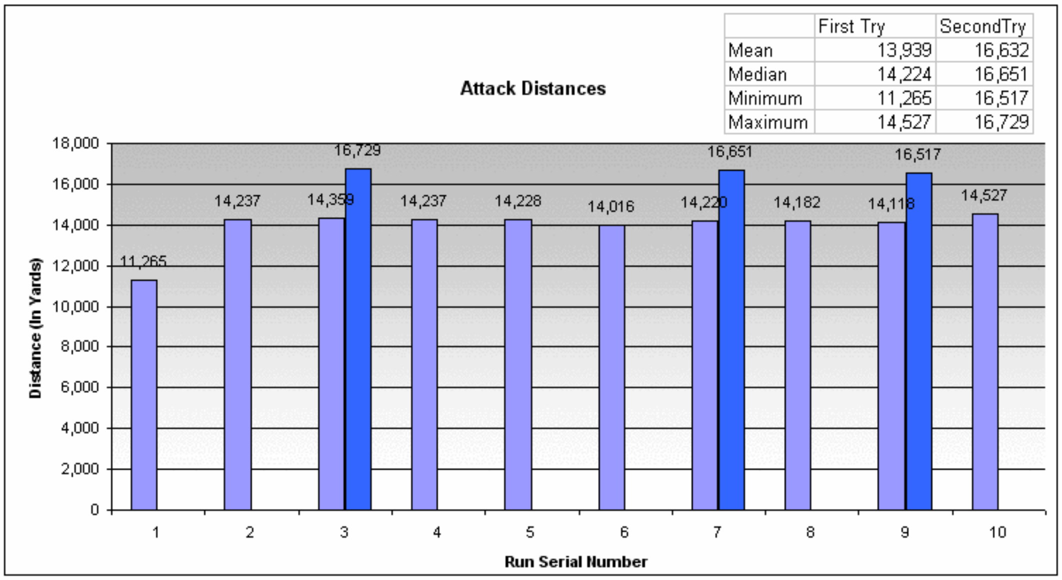


Figure 47. Attack Distances in Each Try

The surface ship's success rate was 77% and the MOE is 0.7 (see Figure 48).

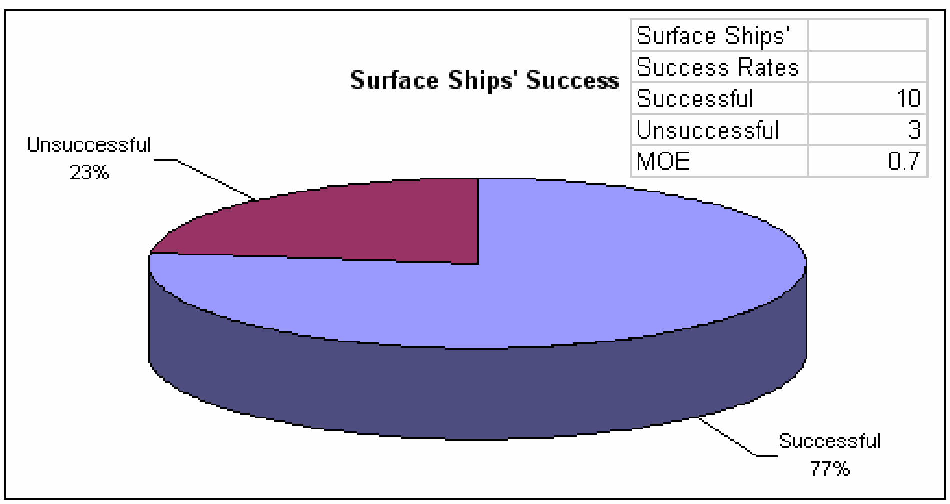


Figure 48. Surface Ships' Success for the Configuration

The surface ships sank the submarine seven times (see Figure 49).

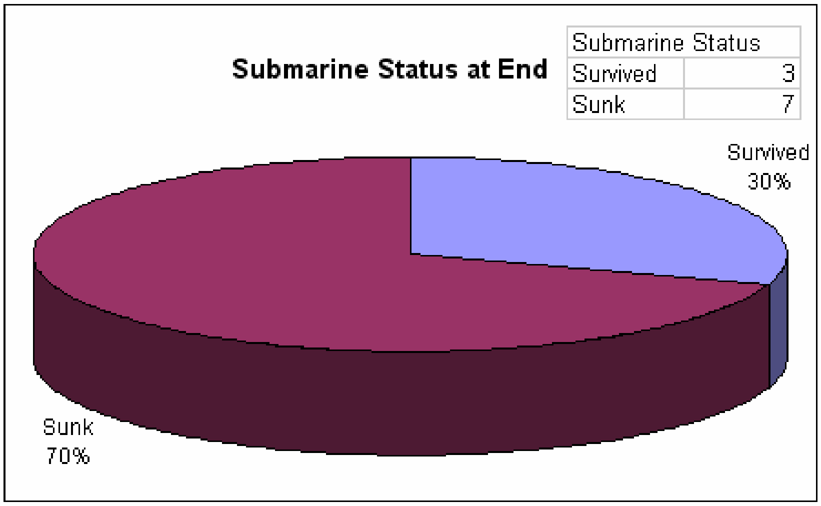


Figure 49. Submarine's Status at End

3. Results for Six Ships (First Configuration)

The submarine attacked the HVU 14 times. It was able to successfully attack the HVU four out of the fourteen attempts. See Table 17 for the results of the attacks.

	Attack Distances		Submarine's Success		Battery Unit at Attack Time (%)		Submarine's Status at End
Run Time Serial Number	First Try	Second Try	First Try	Second Try	First Try	Second Try	
1	12,558	15,119	Unsuccessful	Unsuccessful	60.38	44.82	Sunk
2	12,813		Successful		59.04		Survived
3	13,059		Successful		60.03		Survived
4	13,183		Successful		60.59		Survived
5	12,201		Successful		60.49		Survived
6	12,473		Unsuccessful		58.09		Sunk
7	14,548		Unsuccessful		63.24		Survived
8	13,158	13,368	Unsuccessful	Unsuccessful	59.26	43.76	Survived
9	14,925	14,971	Unsuccessful	Unsuccessful	63.05	41.94	Survived
10	14,348	14,165	Unsuccessful	Unsuccessful	62.96	42.74	Sunk

Table 17. The Results for Six-Ship ASW Configuration

The submarine attacked at distances between 12,201-14,925 yards with an average distance of 13,327 yards (see Figure 50).

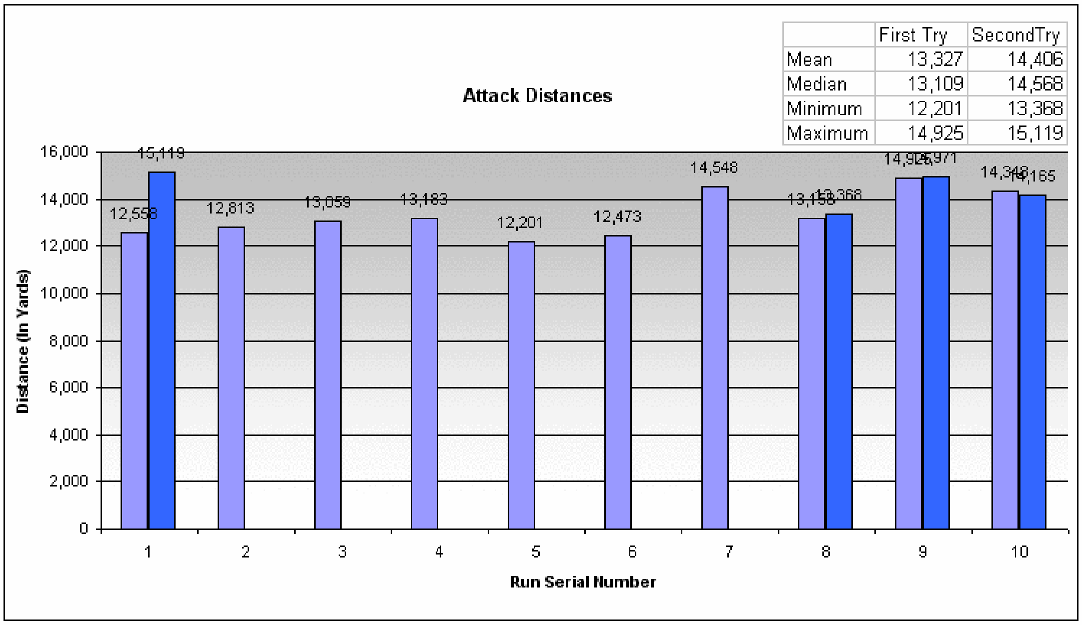


Figure 50. Attack Distances in Each Try

The surface ship's success rate was 71%. The MOE was 0.6 (see Figure 51).

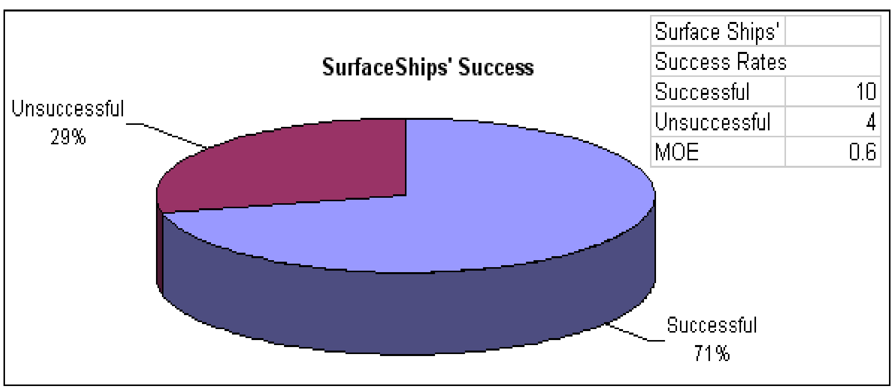


Figure 51. Surface Ships' Success for the Configuration

The surface ships sank the submarine three times (see Figure 52).

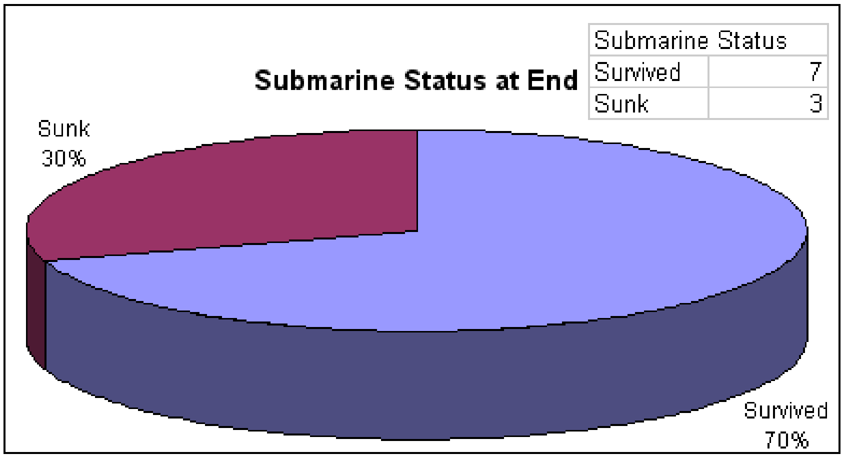


Figure 52. Submarine's Status at End

4. Results for Six Ships (Second Configuration)

The submarine attacked the HVU 12 times. It was successful at attacking the HVU only two out of the 12 attempts. See Table 18 for details on the success rate of the attacks.

	Attack Distances		Submarine's Success		Battery Unit at Attack Time (%)		Submarine's Status at End
Run Time Serial Number	First Try	Second Try	First Try	Second Try	First Try	Second Try	
1	14,229		Unsuccessful		62.13		Survived
2	10,936		Successful		37.08		Survived
3	13,903	16,960	Unsuccessful	Unsuccessful	62.31	45.01	Survived
4	14,340		Unsuccessful		62.3		Survived
5	13,373	16,218	Unsuccessful	Unsuccessful	58.88	42.12	Sunk
6	10,788		Successful		34.25		Survived
7	10,202		Unsuccessful		33.01		Sunk
8	10,128		Unsuccessful		30.73		Sunk
9	11,219		Unsuccessful		36.53		Survived
10	14,122		Unsuccessful		62.56		Survived

Table 18. The Results for Six-Ship ASW Configuration

The submarine attacked at distances between 10,128-12,296 yards with an average distance of 12,234 yards (see Figure 53).

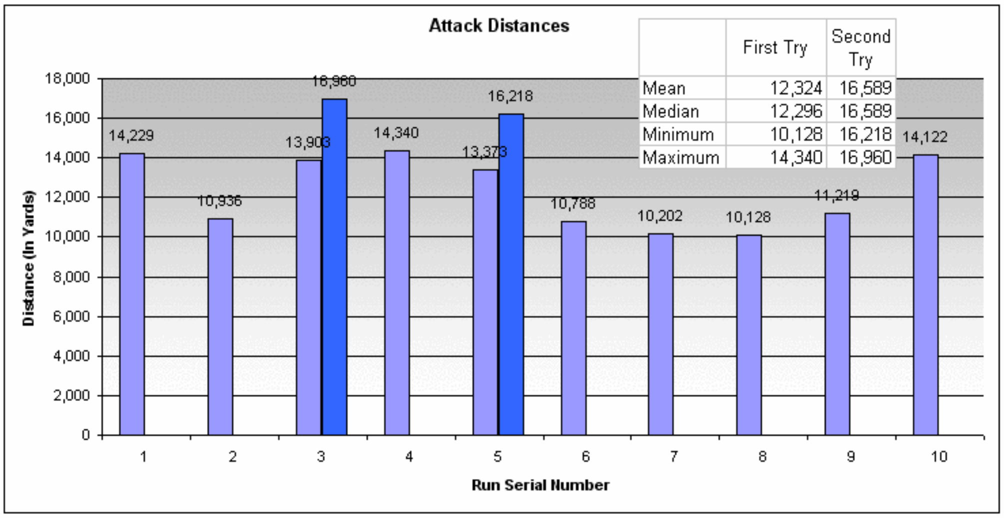


Figure 53. Attack Distances in Each Try

The surface ship's success rate was 83%. The MOE was 0.8 (see Figure 54).

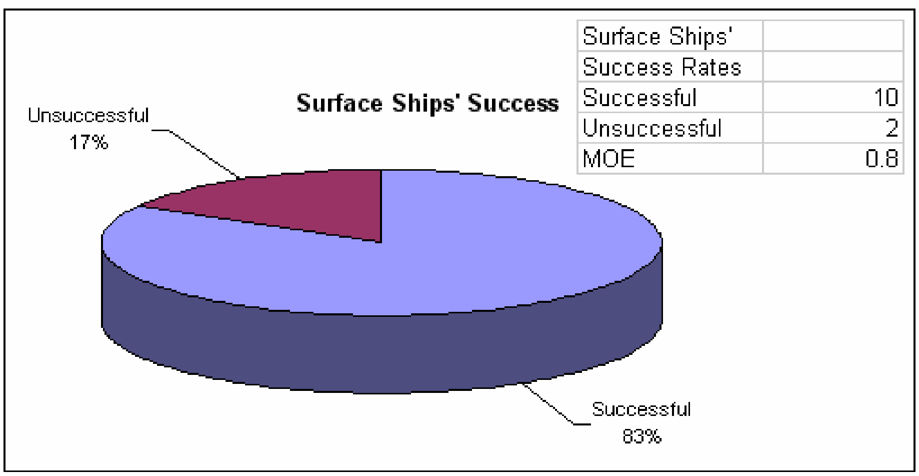


Figure 54. Surface Ships' Success for the Configuration

The surface ships sank the submarine three times (see Figure 55).

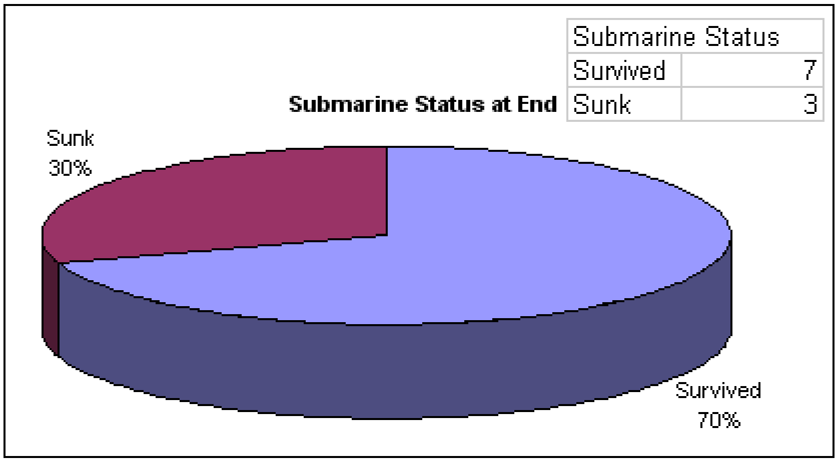


Figure 55. Submarine's Status at End

C. DISCUSSION

The most beneficial feature of a MAS technique is that the outcomes of the simulation have the capability to surprise even its designer. As previously mentioned, the simulation helps the program user by showing the details and events that the user cannot predict or understand without the aid of a visualization tool. The following is a brief analysis of the results of the sample configurations.

The four-ship configuration was the least effective in protecting the HVU (MOE = 0.1). Surface ships protected the HVU only one time. The submarine attacked at the distances: first try at 13,543 yards, second try: 8,659 yards. The greatest disadvantage in this configuration was the large sectors assigned to each ship. As a result, the ships were slow to return to their sectors after searching the DATUM. Even though the submarine was unsuccessful with its attack, the attack forced the escort ships to leave their sectors for the DATUM search. The submarine was able to penetrate the screen at the sectors where the ships had left to search for the DATUM and fire its torpedo within the fatal distance of 10,000 yards. The surface ships could not sink the submarine during any run-time. This was due to the great distance between the attack position and the nearest ship's position. When the nearest ship arrived at the DATUM, the submarine had already moved away. This configuration would be the worst

decision for an ASW commander, since the submarine was able to penetrate the configuration at a fatal distance of 10,000 yards for seven times.

The configuration with five ships provided a MOE value with 0.7. The submarine attacked at two distances : first try at 13,939 yards and second try at 16,632 yards. If the submarine failed in its first try, it also failed at its second try. The ship was successful in protecting the HVU by creating a barrier between the HVU and the submarine. The surface ships prevented the submarine from approaching the HVU at a close range (14,000 yards) on all attempts except for one. The submarine was forced to fire the second torpedo from a greater distance than the first torpedo attack. The submarine was destroyed seven times. The success rate for the surface ship was 77%.

The configuration for the six ships was not as effective compared to the second configuration (MOE = 0.6). The submarine attacked at tow distances: first try at 13,327 yards and the second try at 14,406 yards. A user who is not familiar with ASW Screen Configuration might predict that increasing the number of ships would yield a greater MOE and attack distances. However, this proved not to be the case in this simulation. The disadvantage of this configuration was that the outer sector was so broad (90°) and quite large for a ship to cover. The submarine could attack at the opposite corner of the sector of the ship's position. The submarine was sunk only for three times and the success for the surface ship was 71%.

The second configuration with six ships (two ships were assigned to outer sectors) provided the highest MOE value within the four sample configurations in this experiment (MOE=0.8). The submarine attacked at the distances: first try at 12,324 yards and second try at 16,589 yards. The submarine was not able to penetrate the ASW screen several times; therefore, it canceled these attacks since it sensed a very close ship but did not have sufficient time for a fire solution. The submarine consumed more battery every time it tried to attack and then cancelled since it is moving at 20 knots to assume an attack position. For this reason, the submarine had only one chance for an attack. The submarine's

decision surprised the user since it risked its own safety and approached the HVU for an attack though it had a low battery level. The submarine fired a torpedo at distances of 10,000 to 11,000 yards when it came close to the HVU. The submarine was sunk three times and the success rate for the surface ship was 83%.

The program user will decide the best configuration based on the results of the model. The user will consider the MOE value to determine the success rate of protecting an HVU. However, in configuring an ASW screen, the ASW Commander must also consider the distance between the submarine and the HVU during an attack. Therefore, the configuration that provides the second highest MOE value, but forces the submarine at a greater distance from the HVU, could be considered an alternate. To be able to test whether the MOE (0.7) is significantly different from the highest MOE value (0.8) or not, a null hypothesis should be defined, and a t test should be applied. The null hypothesis and alternative hypothesis is defined below.

$$H_0: \ MOE_{0.8} = MOE_{0.7}$$

$$H_a: \ MOE_{0.8} > MOE_{0.7}$$

The significance level (α) is 0.05, the standard deviation can be determined by the following equation [15]

$$\sigma = \sqrt{\frac{MOE \times (1-MOE)}{n}}$$

and t-value can be calculated from the following equation:

$$T = \frac{\bar{X}-\bar{Y} - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{m} + \frac{s_2^2}{n}}}$$

[15] Devore, J. L., 1999, *Probability and Statistics*, 5th Ed. Duxbury Inc., p 366.

The t-value for this test is 1.64 and the degree of freedom can be determined by the following equation:

$$v = \frac{\left(\frac{s_1^2}{m} + \frac{s_2^2}{n}\right)}{\frac{\left(s_1^2/m\right)^2}{m-1} + \frac{\left(s_2^2/n\right)^2}{n-1}}$$

The degree of freedom value is 17.6 and $t_{.005,17.6} = 1.74$

Since the t-value calculated is less than the t-value from table-value, there is not enough evidence to reject the null hypothesis described. Statistically, there is not significant difference between MOE value (0.8) and MOE (0.7). Because of the lack of significant difference, the configuration that provides the second highest MOE (0.7) value, because it forces the submarine at greatest distance from the HVU, would be chosen. In this configuration (MOE 0.7) the submarine does not penetrate the ASW screen. At the end of the experiment, the configuration for five ships yielded the best overall results for HVU protection. Although the MOE (0.7) was not significantly different from the best MOE value (0.8), it provided the greatest distance between the submarine and the HVU at the time of attack (13,939 yards) and in effect, the best protection.

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VI. CONCLUSIONS

The following description outlines the success of the model, possible applications in ASW operations, and discusses the need for further research.

A. SUCCESS OF THE MODEL

The model can be used to aid in ASW military operations for the Turkish and NATO Navies. This is especially true for navy operations that are restricted by shallow waters—characteristic of the Mediterranean and Aegean Sea—since the shallow depth prevents effective use of Towed Array Sonar (TAS). The simulation allows the user to test parameters that correlate with real life variables. A submarine's maximum speed and passive sensor range, as well as a torpedo's maximum range, used in the model, are characteristics of current submarines. Hence, the results derived from the simulations will be very similar to actual ASW operations. The model can be used to train ASW personnel and aid commanders in deciding and planning an optimal ASW screen configuration for ASW operations.

The model provides military personnel with information on submarine movements that they would not otherwise be able to detect in actual ASW operations. For example, they would not know when the submarine begins attack procedures. In actual ASW training, the submarine commander's decision to release attack information is usually delayed (approximately five minutes after initial submarine attack) and the submarine's position is known by the surface ships only after the submarine communicates its attack via underwater telephone. Hence, the surface ship personnel know of an attack only after that communication. Following actual training, the submarine commander, surface ship commanders, and ASW officers may convene to analyze the outcomes of the training. However, they will not be able to plot all the ships' and submarines' positions for a thorough analysis. The simulation model will be a critical tool for improving the training and analysis of the effectiveness of an ASW operation.

The findings of the training from the simulation model can then be distributed to experts who can verify the accuracy of the findings and compare them to actual ASW operations.

B. POSSIBLE APPLICATIONS OF THE MODEL

1. Training

The model can be used by ASW experts as well as someone who has very little knowledge of ASW operations. The model allows the program user to experiment with ship configurations to improve the MOE. A user can attempt to configure an optimal ASW screen by employing the following strategies:

1. Changing the perimeters and boundaries of the frontal ships.
2. Positioning one or two ships to outer sector.
3. Changing sonar policy.
4. Increasing the convoy speed.

The model allows the user to obtain information on the conditions when a submarine decides to fire a torpedo and when it will cancel an attack. The user will try to force the submarine to fire the torpedo at a distance greater than 15,000 yards. A submarine attack at a distance greater than 15,000 yards yields the lowest probability for a successful attack. At the same time, the user will consider one element of cost-effectiveness by minimizing the number of ships in the configuration.

2. Decision Aid

The model can be used as a decision aid for planning an ASW operation. To configure an ASW screen, the commander must first determine the sonar ranges for the simulation. The commander can obtain the sonar range by first collecting stored data from previous years about water temperatures at the time of the operation. The data on the water temperature and sonar range can be retrieved from a bathythermograph. The bathythermograph shows the water temperature change with a depth of up to 2,000 meters. The commander will then run the model to obtain the number of the ships and the ASW screen

configuration needed for the ASW operation training. If the previously input sonar range values differ from the actual values on the training day, the commander will run the model with the actual sonar range values and change the number of ships and screen configuration accordingly. At the end of the training, the model outcomes can be compared to actual ASW findings. The accuracy of the outcomes from the simulation can be verified by the actual data from the ASW operation.

C. FUTURE WORK

1. Possible Improvements to the Model

The greatest deficiency in the present model is that it does not simulate the water layer and its effect on hull-mounted sonar. A layer can significantly compromise the effectiveness of hull-mounted sonar to detect a submarine under the layer. The active sonar used by surface ships is considerably affected by water conditions. The sonar devices are small and underdeveloped compared to the submarine's sonar devices. In future models, water conditions can be simulated to show their effects on the surface ship's sonar and its detection of submarines.

In this model, the submarine targets only the HVU for an attack, but in reality, every surface ship in the formation is a potential target. Actually a submarine can penetrate the ASW screen by deciding to attack any surface ship in the formation. If the submarine is successful attacking a ship or a ship moves away from its coverage sector, the ASW screen's effectiveness will be diminished by gaps in protection. The submarine can then advance towards the HVU for a kill. As described above, a submarine's movement in an actual ASW operation is more complex than accounted for in the simulation.

2. Expanding to Other Military Operations

The current program does not implement Marine Patrol Aircraft (MPA). Using sonobuoys from the MPA and a helicopter can enhance the effectiveness of the overall success of HVU protection from submarine attacks.

The use of the present program can be extended to simulate other types of warfare such as Anti-Surface Warfare (ASUW) and Anti-Air Warfare (AAW). ASUW and AAW operations are more critical in the case of attacks from enemy planes or ships. The same logic for implementing simulations for ASW can be applied to ASUW and AAW.

In the future, the program's submarine artificial intelligence or decision algorithm can be further developed with advice and guidance from the submarine commander. The commander's input in developing the submarine's artificial intelligence and algorithm should be covered by national security to protect the model from being used by other countries. This will ensure the security of the ASW operation for the particular country using the simulation technology.

APPENDIX A EXTENSIBLE MARK-UP LANGUAGE (XML) FILES USED IN THE SIMULATION

A. READING AND WRITING TO EXTENSIBLE MARK-UP LANGUAGE (XML)

In the simulation Extensible Mark-up Language (XML) files were created to store data and initialize the parameters. Data can be stored in an XML file for easy access, and XML structures force the data to be stored with a restricted format. To be able to read and write data in XML files the JDOM package is used. JDOM is an open source-library, pure Java API for parsing, creating, manipulating, and serializing XML documents. JDOM source code and the instructions for installation can be obtained from JDOM.org web page.[16]

XML files used in the program are saved in the hard drive under a folder XMLFiles, the default file path is "C:\ASWDesign\ASWDesign\XMLFiles\". Each file is saved under a different folder. For example ASWArea files are stored in "..\\XMLFiles\AreaData\", and similarly ASWScreen files are stored under "..\\XMLFiles\ScreenData\"

B. TYPES OF XML FILES IN THE SIMULATION

1. ASW Area File

ASW Area File has two elements : NumberofPoints and Point. A point Element is also has three elements: ID, Lat, Long (see Figure 56). In the simulation the ASW Area is 35 x 50 nautical miles (NM).

[16] Hunter J., cited 2004, JDOM source, [Available online at http://www.jdom.org/downloads/source.html.]

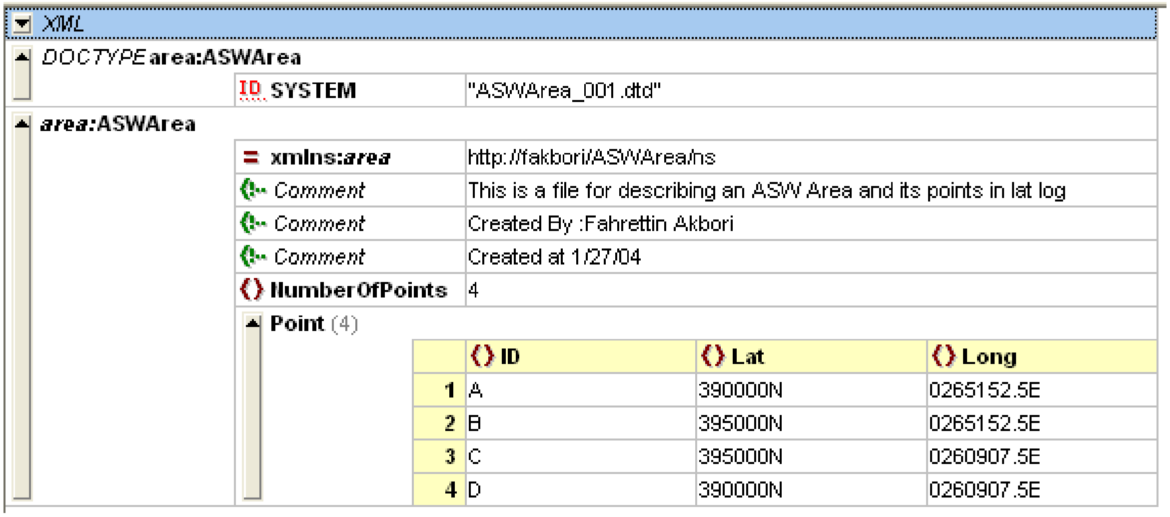

Figure 56. ASW Area File Shown in Grid

2. ASW Screen File

ASW Screen File has four or more sector Elements. Each sector element has eight elements: ID, Name, Screen Value, Starting Bearing, Ending Bearing, Staring Range, and Ending Range (see Figure 57).

	ID	Name	S...	Sta...	End...	Start...	EndR...	Inn...
1	1	Yavuz	1	0	90	5500	10000	true
2	2	TurgutReis	2	90	180	4500	9000	true
3	3	Fatih	3	180	270	4500	9000	true
4	4	Yildirim	4	270	359	5500	10000	true
5	5	Barbaros	5	300	359	11000	16000	false
6	6	OrucReis	6	0	60	11000	16000	false

Figure 57. Screen File Shown in Grid

3. ASW Zigzag Policy File

ASW Zigzag file has a date element and a pattern element. A pattern Element has three elements: a start time, end time, and course change from main course (see Figure 58).

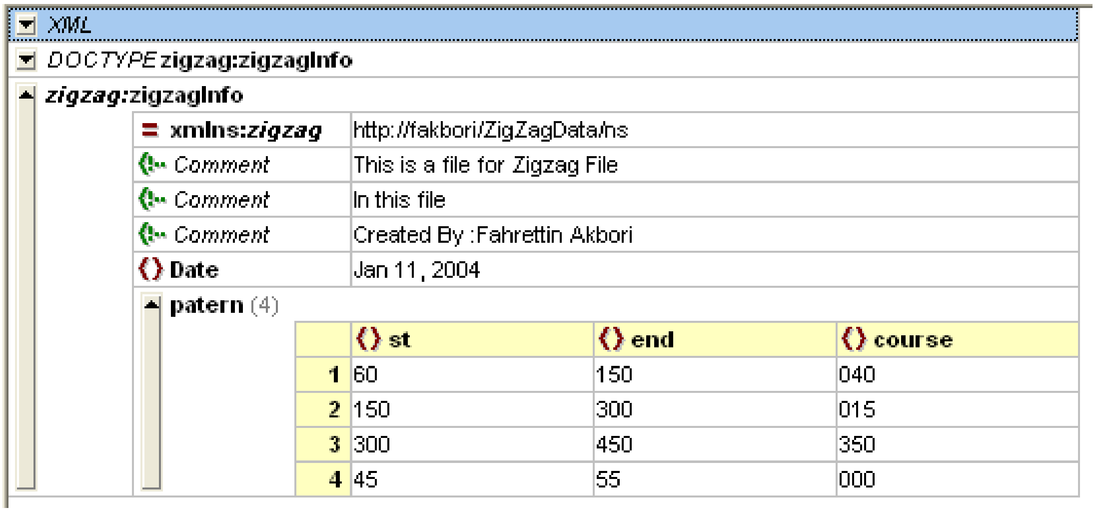

Figure 58. Zig-zag File Shown in Grid

4. ASW Sonar Policy File

ASW sonar policy file has 2 elements: Date and Ship, a Ship element can be as many as ships used in the simulation. Each ship element has two elements: ID, and Active. Each active element should have a start time and end time (see Figure 59).

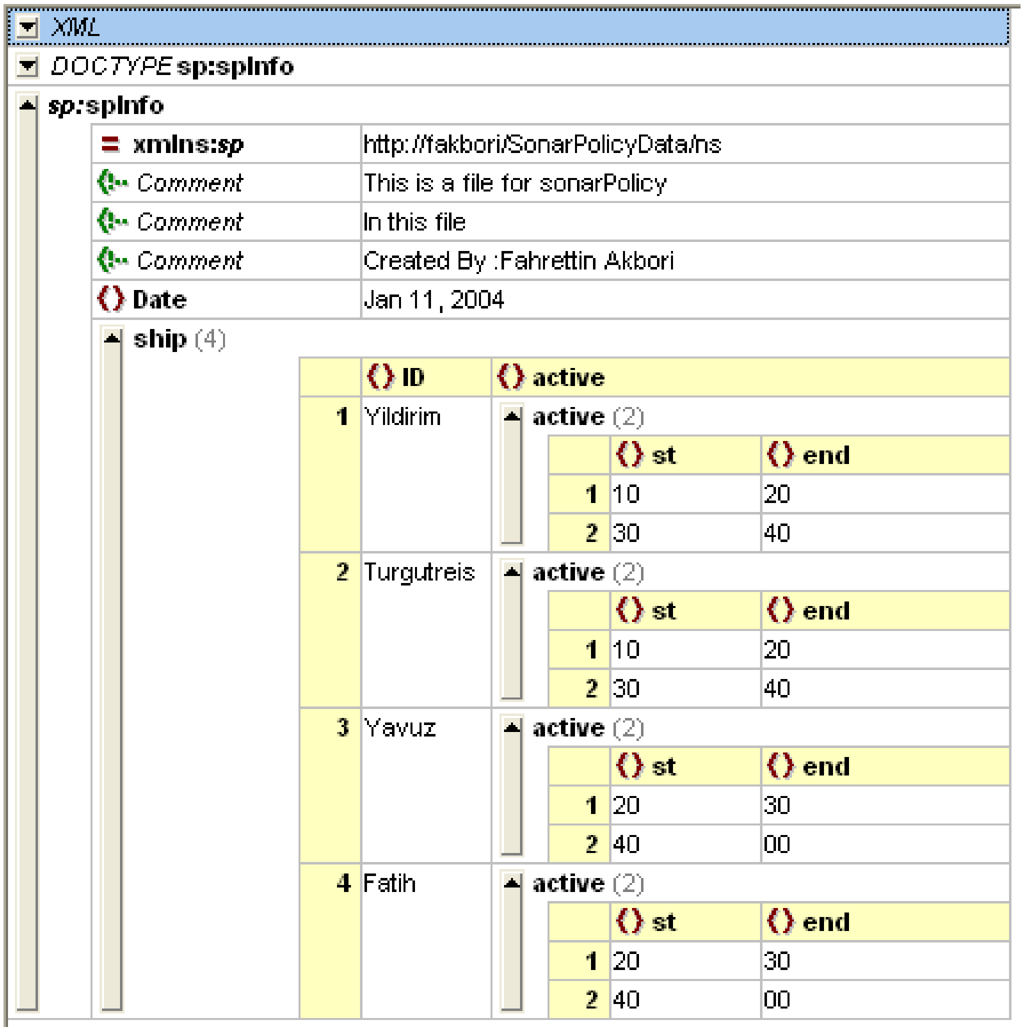

Figure 59. Sonar Policy File Shown in Grid

5. Ship Characteristics File

Ship characteristics file has ship elements. A ship element has Name, Type, Hull-number, Call-sign, Sensors, Weapons and Helicopter Elements. Each sensor element consists of a sonar element. A sonar element has three elements status, type, and maximum range fields. Each weapons element consists of torpedo elements. A torpedo element has two fields: type and quantity. Helicopter elements have two fields: tail number and status field (see Figure 60).

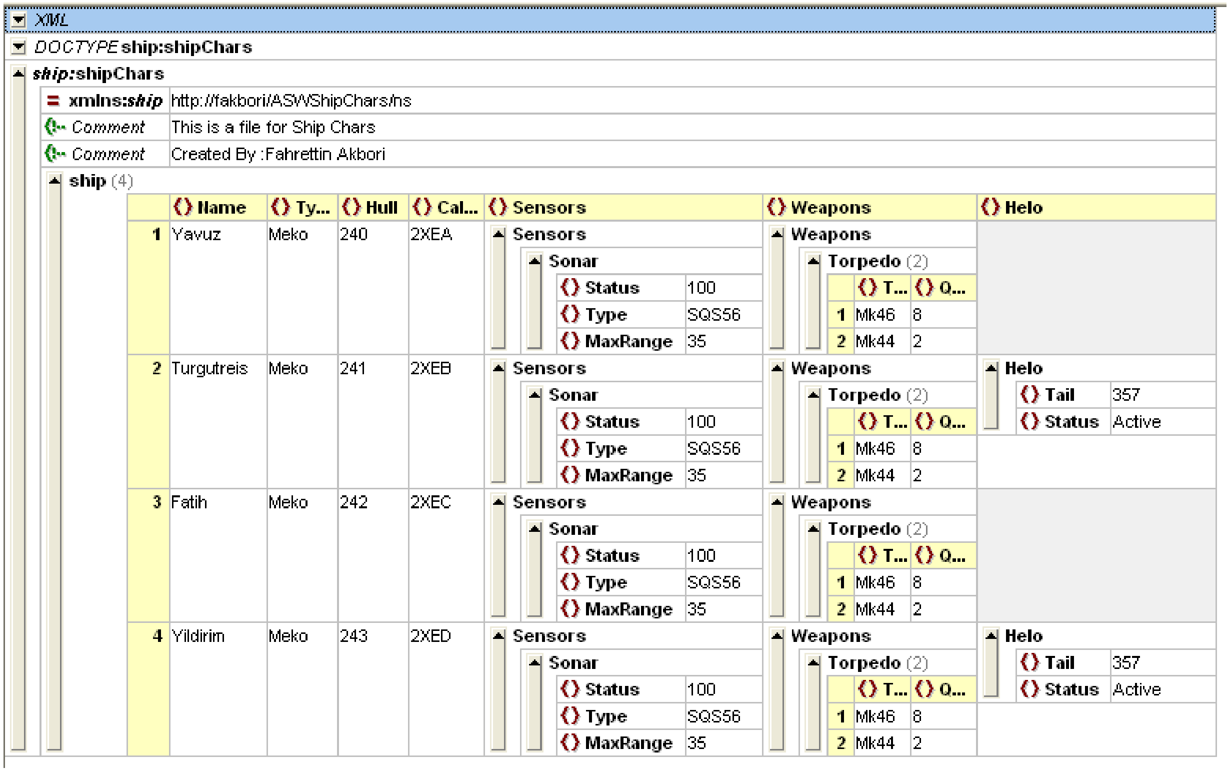

Figure 60. Ship Characteristics File Shown in Grid

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APPENDIX B GENERATING RANDOM NUMBERS

A. SIMKIT PACKAGE

In this simulation, random numbers are generated by Simkit package. Simkit is a library for creating a Discrete Event Simulation (DES) models. The Simkit package is written in Java programming language, and used as a teaching tool for Masters' students in Operations Research and MOVES at the Naval Postgraduate School in the System Simulation course. Simkit is free software and can be obtained from the Simkit home page.[17]

B. GENERATING RANDOM NUMBERS

In the simulation, two types of distributions are used for drawing random numbers:

1. Normal Distribution
2. Uniform Distribution

1. Normal Distribution

Normal distribution is used to determine the sonar ranges for medium- and long-range sonar. The default maximum and minimum values for medium-range sonar are 3,000 to 7,000 yards. The parameters to generate a random number for this type of sonar are mean value: 5,000 and standard deviation: 588.23. For every distribution, a seed value will be generated as a function of system time.

seed value=(system second x 1000) + system millisecond

2. Uniform Distribution

Uniform distribution is used to randomly position the submarine within two-thirds of the ASW area. It is also used to determine the submarine's torpedo attack success rate. A uniform random number between 0.0 and 1.0 can be calculated from inputting the parameters (0.0 and 1.0) and a seed value.

[17] Buss A., cited 2004, Simkit home page, [available online at http://diana.or.nps.navy.mil/Simkit/]

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